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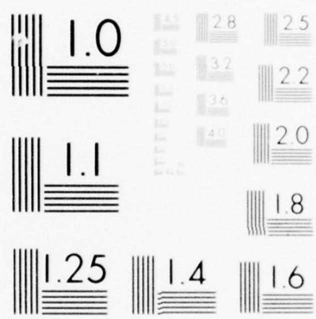

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REPORT ONR-CR213-142-1F

OFFICE OF NAVAL RESEARCH

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SIMULTANEOUS SENSOR PRESENTATION TECHNIQUES STUDY

HUGHES AIRCRAFT COMPANY
CENTINELA AND TEALE STREETS
CULVER CITY, CA 90230

FINAL REPORT FOR PERIOD 1 JUNE 1976 TO 30 JANUARY 1977

JULY 1977

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This study investigated the utility and feasibility of combining imagery from several airborne sensors and data sources on a single real-time display. The baseline sensors and data sources considered for an advanced, high performance attack aircraft included radar, FLIR, TV, laser spot tracker/designator/ranger, warning receivers, a priori data (cartography, target/threat coordinates, reconnaissance imagery of target) and data-linked

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20. ABSTRACT (Continued)

target/threat information. Several promising simultaneous data presentations were determined for use within the key phases of an interdiction mission. These were simulated by the superposition of static imagery and qualitatively evaluated. The mechanization complexity of implementing each display combination, as well as a highly flexible general system implementation, was examined. It was concluded that all of the key hardware elements required are presently available or in development. Many are already onboard or scheduled for incorporation in tactical aircraft and may be time-shared for the display of multisensor information.

SUMMARY

The primary objective of the Simultaneous Sensor Presentation Techniques Study was to investigate the utility and feasibility of combining imagery from multiple airborne sensors and data sources on a single real-time display. To provide a framework for the study, a single-seat, high performance attack aircraft was assumed, having a sophisticated avionics suite, ordnance capability for the complete range of conventional, laser/EO-guided and anti-radiation weapons, and a full complement of advanced sensors for the air-to-ground (and air-to-air) combat role.

To identify the types of information which might be synergistically combined and displayed during a typical mission, the interdiction mission was selected for detailed analysis. Interdiction depends heavily on precise navigation, penetration tactics, and self-contained target acquisition and weapon delivery. This places a severe task loading on the pilot. Because his performance of visual and manual tasks during these critical mission phases requires the simultaneous utilization of a variety of real-time sensors, a priori data, and possibly data-linked information, it is here that the optimized display of multiple sets of information may best serve the operator.

By consideration of the mission profiles, the operator tasks required per mission phase, and the capabilities of the baseline sensors available to the operator, an extensive number of possible data combinations emerged. A qualitative evaluation of these combinations, based on estimated utility to the operator and complexity of implementation, has resulted in several candidate simultaneous data presentations which are recommended for further study:

- The simultaneous display of real-time radar ground map and stored cartography and waypoint data to assist in accurate navigation to the prebriefed target area.
- The simultaneous display of real-time radar ground map and stored reconnaissance imagery of prebriefed targets for preliminary target acquisition at long range, for target verification, and for offset aimpoint designation.
- The simultaneous display of real-time radar ground map and real-time FLIR data at long stand-off ranges to provide thermal gradient indications for cuing the operator to possible targets

on the radar display. This could be particularly valuable for the acquisition of large target complexes or for hot spot detections corresponding to targets of opportunity such as moving vehicles.

- The simultaneous display of real-time FLIR imagery and radar glints for cuing the operator to man-made objects on the FLIR display which could be cold or hot.
- The simultaneous display of real-time FLIR and real-time TV, processed and mixed in an optimum fashion such that certain types of targets may be acquired in shorter time or at longer range.

A general system implementation for achieving all of these combinations in real time has been conceived. The system will accept inputs from any of the above sensors and data sources, will spatially warp and register any two desired images, will perform various selectable enhancing operations on one or both images, and will present the combined data on a single display. The relative complexity of mechanizing each individual combination is also considered. In practice, an operational system will undoubtedly implement only a limited number of the processing operations shown in the general system, depending on the types of information to be combined, specific performance and accuracy requirements, desired flexibility, and permissible hardware size, weight, and power. It should be noted that much of the hardware shown in the general system implementation (and thus the austere systems also) may already be onboard a high performance tactical aircraft and may be time-shared for use in the display of multisensor information. Thus, the incorporation of a simultaneous presentation capability need not mean a major addition of avionics. Also, all of the elements identified in the general and austere systems represent equipment that is available or presently in development.

Future efforts to confirm and quantify the results of this study should include: 1) the acquisition of simultaneous coincident coverage multisensor imagery of tactical targets in various backgrounds; 2) the spatial warping and registration of that imagery; 3) the application of a variety of image processing and enhancing operations; 4) the display of the registered, processed data with a variety of video mixing techniques and false color combinations, and 5) the quantitative evaluation of the resulting simultaneously presented imagery by a human factors study.

PREFACE

This final report covers the work accomplished during the period June 1976 through January 1977 under Contract N00014-76-C-0802 entitled Simultaneous Sensor Presentation Techniques Study. This work was supported by the Office of Naval Research under the sponsorship of Commanders Don Hanson and Stacy Holmes.

The work was accomplished by the Display Systems Department under the technical direction of T. A. DuPuis. Special acknowledgement is given to the following individuals who contributed to the project: M. L. Hershberger, A. J. Mendez, E. W. Opittek, M. D. Pruznick, J. Savage, A. A. Sawchuk, and J. Tylka.

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1.0 INTRODUCTION

1.1 BACKGROUND

Future military engagements in all probability will see the U.S. forces handicapped by 1) the enemy enjoying global and local numerical superiority and 2) the enemy having the advantage of first strike and, consequently, momentum. Thus, the U.S. must depend heavily on using superior technology and sophistication in its tactical equipment to generate highly mobile and concentrated firepower, so that the enemy thrust can be first blunted, then repelled.

The superior technology and sophistication in equipment must manifest itself in all combat phases, from reconnaissance and staging to navigation, target acquisition, weapon delivery and damage assessment. The sensor equipment involved is usually related to extending the man's capability to sense the battlefield situation, typically by means of passive and active sensors and associated data processors and displays. In most cases, a man will remain in the loop to monitor and interpret the output of these sensors.

Experience has shown that increasing the number of airborne and groundbased sensors can result in an increased probability of successful target acquisition because of a target's multi-spectral attributes. The multisensor approach circumvents enemy attempts to make use of stealth and camouflage, since all target signatures cannot be viably reduced simultaneously. The advantages of multisensor utilization in air-to-ground combat were well demonstrated in the highly successful AC-130 Gunship operation in Vietnam, followed by Tropic Moon III, and leading to the current Target Recognition/Attack Multisensor (TRAM, A-6E and A-7E) in the Navy, and Pave Tack and Quick Strike Reconnaissance (QSR) in the Air Force.

As the number of sensors and avionic subsystems increases, however, the amount of information which must be displayed, controlled, and assimilated by human observers is also increasing. Thus, a severe task loading problem is developing, particularly in attack aircraft where mission success is strongly dependent on penetration tactics and self-contained target acquisition and weapon delivery. The problem is intensified during nighttime missions. In addition, many of the weapon platforms are single seat aircraft

(A-7, A-10, F-15, F-16, F-18/A-18, A-4M, etc.), thereby placing the burden of navigation, threat detection and defensive action, target acquisition and weapon delivery on a single operator.

There is an immediate need to maintain the advantages of multisensor target acquisition while coping with the task loading limitations imposed by single seat air-to-ground combat. In the past, each sensor has typically had its own dedicated display and observer (Gunship, for example). Human factors studies have shown, however, that the grouping of several sensor displays for target recognition purposes by a single observer utilizing several sensors actually results in increased recognition time, probably because the observer spends much of his time searching the displays. These results, combined with instrument panel space limitations, have led to time-sharing of sensor inputs on a single common display surface. This technique requires a visual "reorientation" at each sensor change, and also the manual switching of sensor images for "best" sensor selection. The system could be automated; however, the programming of such timesharing may be quite critical. Clearly, innovative techniques are required to provide the pilot with the salient information he needs from each sensor at appropriate points in the mission timeline and in a readily interpretable manner.

The study reported herein examined techniques for combining multiple sensor data in an effective and timely manner for simultaneous display on a single display surface. A key objective was to define those simultaneous sensor presentations (using techniques which can be practicably implemented) which have the potential to increase the probability of successful target acquisition and weapon delivery, improve survivability, and achieve a high level of mission performance with a reasonable operator task loading.

1.2 STUDY APPROACH

This general problem has been rendered addressable in this study by concentrating on 1) a high performance, single-seat attack aircraft, and 2) a single class of airborne missions which imposes a severe task loading on the operator, i.e., the interdiction mission for prebriefed fixed targets and for targets of opportunity in prebriefed target-rich areas. The study approach was to divide the interdiction mission into key phases, define the operator tasks per mission phase, and determine the information required to perform those tasks.

An extensive list of applicable sensors was surveyed in terms of operational parameters, detectability of types of targets, and typical range capabilities. The information requirements of the various interdiction mission phases were then used to select or "filter" the list of candidate sensors and sensor modes. This approach placed the performance requirements and sensor selection in context, and reduced the large set of applicable sensors to a small set of baseline sensors which are reasonably affordable and hence realistic.

The baseline set of sensors were then analyzed with respect to possible simultaneous presentation for each phase of the mission including cruise/ navigation, preliminary target acquisition, run-in to target, and target acquisition/weapon delivery. From this analysis emerged a primary or "lead" sensor for each mission phase, a set of secondary sensors, and a set of required or desired supplementary data. Various techniques were considered for combining primary and secondary sensor data on a single display including 1) overlaying one sensor image upon another, 2) deriving "highlight" data from one sensor and displaying it as an overlay on another, and 3) using overlay symbology to represent target or threat locations as determined from onboard sensors, as data-linked to the aircraft, or as called up from a priori data stored in the aircraft data base. (A literature search was conducted to ensure that results of previous studies in this area could be evaluated and taken into consideration in the present study where applicable.)

The relative merits of these candidate combinations were subjectively evaluated by means of synthesized and simulated video combinations, statically displayed in black and white and in color. Various processing or enhancing operations which can be applied within each combination were also considered. Based on an examination of each possible combination in terms of potential utility to the pilot and relative complexity of implementation, the most promising combinations that emerged include the simultaneous presentation of 1) radar video and cartography, 2) radar video and stored reconnaissance imagery, 3) radar video and FLIR or TV video, and 4) FLIR video and TV video. In all cases, supplementary data can be displayed by the overlay of appropriate symbology.

The implementation of the simultaneous sensor presentations was examined in terms of: preprocessing of the two sensor video to make them

format-compatible; registration of the multisensor images or data; image processing to suitably enhance or extract highlight information from either sensor image; and finally the mixing and display of the two registered, processed sensor video in an optimum manner. A multisensor system concept was described for accomplishing the various correction and processing operations in real time with flyable equipment. The system is modular in nature, microprocessor controlled and highly programmable, and makes maximum use of processing/display elements already onboard advanced aircraft or scheduled for future incorporation. In addition to the general system implementation, the relative complexity of implementing individual candidate combinations was also examined. The study concludes with recommendations for future effort, including hardware development, the simultaneous acquisition of coincident coverage imagery by multiple sensors, and a subsequent dynamic simulation and evaluation of the recommended multisensor combinations.

The following sections present the mission analysis, the methodology used to select multisensor candidates, the description of candidate simultaneous sensor presentations as a function of mission phase (including synthesized imagery), the image processing considerations for multisensor combinations, implementation considerations and typical system operation, and summary and conclusions. The results of the literature search are presented in the appendix.

2.0 MISSION ANALYSIS

A mission analysis was conducted to establish a framework for the definition of possible simultaneous sensor combinations and their subsequent evaluation. The new VFAX strike fighter aircraft, the Navy F-18 aircraft, was selected as the primary vehicle for the mission analysis. The approach was to determine those mission phases and associated operator tasks wherein simultaneous sensor presentation techniques might be employed to improve pilot performance and/or reduce operator task loading. This section includes:

1. Discussion of an F-18 aircraft air-to-ground combat mission (interdiction),
2. Description of the F-18 avionics suite including sensors, displays, and ordnance, and
3. Description of a functional block diagram of the avionics subsystems for air-to-ground combat modes.

2.1 MISSION SELECTION

The Navy F-18 aircraft is a single place, twin engine, high performance fighter/attack aircraft. Its size falls between the A-7 and F-4 and is intended to eventually replace these aircraft. The avionics system is designed around one-man operation.

The F-18 is designed for both aircraft carrier and conventional land takeoff and landing. The aircraft carrier launch/recovery cycle is on the order of 116 minutes, which represents the unrefueled endurance of contemporary aircraft. Marine Corps missions from deployed shore bases will be shorter in duration, on the order of 85 minutes, because distances from the launch/recovery point to the combat zone are shorter than for carrier deployed aircraft. Maximum aircraft speed will be about Mach 1.6 with a combat speed of Mach 0.9.

Six primary missions are postulated for the F-18 aircraft: fighter escort, self-escorted interdiction, combat air patrol, close air support, deck-launched interceptor, and ferry missions. The typical Navy mission is assumed to be air-to-air combat at 10,000 foot altitude; the typical USMC

mission is assumed to be close air support/ground attack at sea level altitudes. For this analysis, the interdiction mission was selected for detailed analysis because it includes mission phases and operator tasks which require the simultaneous utilization of a variety of sensors. Thus, it is during these mission phases that mission performance is most likely to be improved by optimized sensor display techniques, including simultaneous sensor presentations on a single display.

The interdiction mission involves ground attack against prebriefed fixed targets whose coordinates are known and against targets of opportunity (stationary or moving) in a prebriefed target-rich area. Both cases require precise navigation and depend heavily on penetration tactics and self-contained target acquisition and weapon delivery. Thus, in both forms of interdiction missions, the single seat attack operator must deal with a high level of task loading, stemming from the simultaneous requirements of survivability and successful target acquisition and weapon delivery. The task loading is further intensified in night operations. The goal of this study, then, is to define those simultaneous sensor presentations (using techniques which can be practicably implemented) which have the potential to improve survivability, increase the probability of successful target acquisition and weapon delivery, and achieve all of these objectives with a reasonable operator task loading.

The interdiction mission includes 12 mission phases as illustrated in Figure 1:

1. Takeoff
2. Climb
3. Cruise
4. Descent to sea level
5. Run-in to target
6. Air-to-ground combat
7. Run-out
8. Climb
9. Cruise
10. Descent to sea level
11. Reserve (sea level loiter)
12. Land

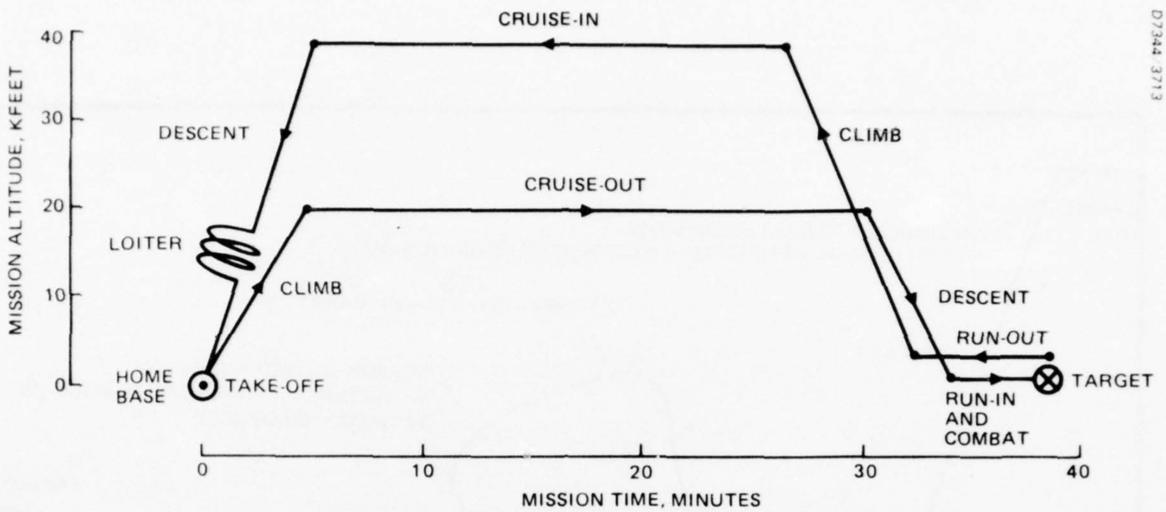
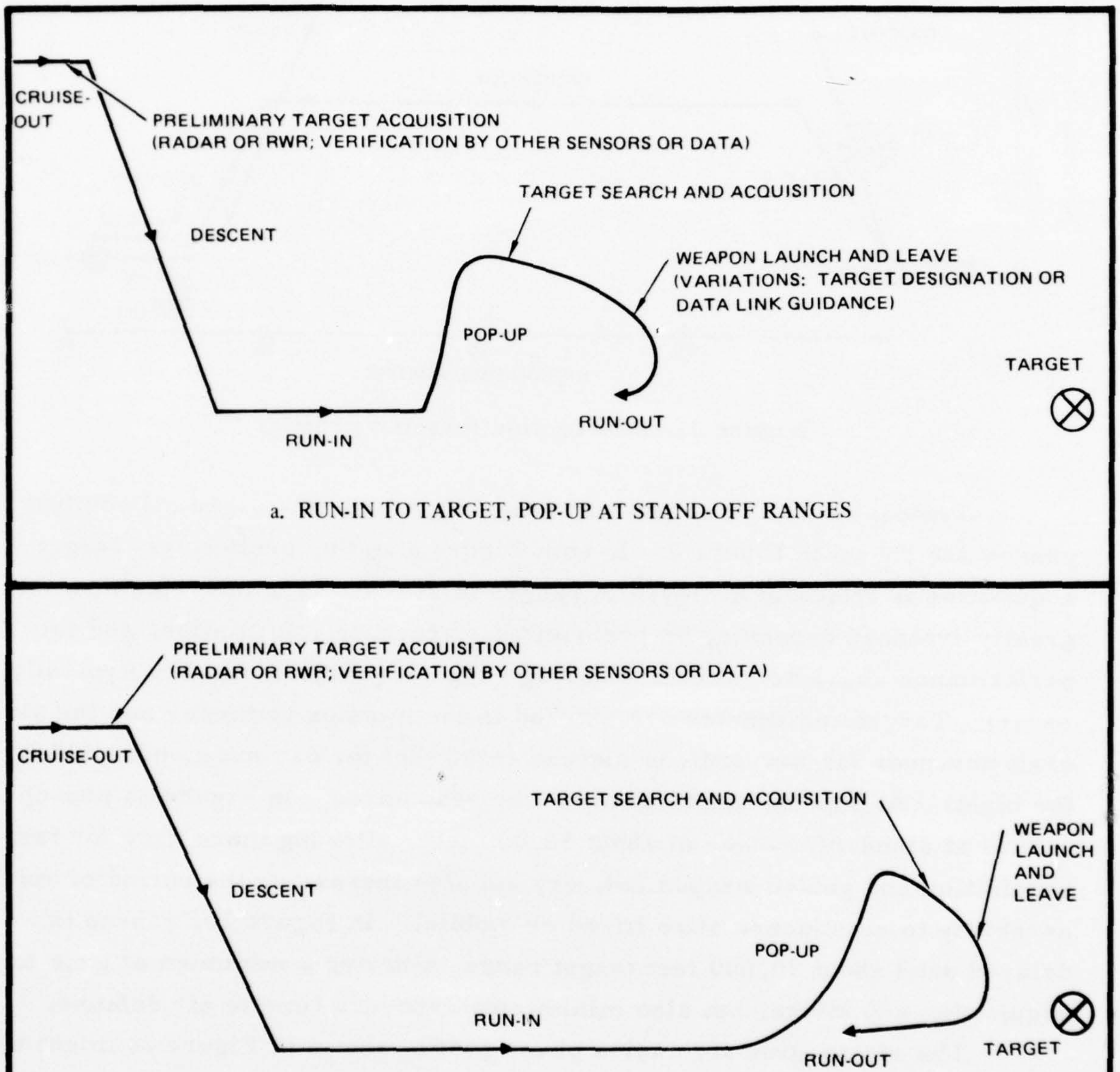


Figure 1. Interdiction mission profile.

Typical variations in the run-in to target and air-to-ground combat phases are shown in Figure 2. In both Figure a and b, preliminary target acquisition is typically achieved at ranges of at least 15 n. mi. which can be greatly extended depending on prebriefing, targetting information, and the performance characteristics of the long range acquisition sensors (typically radar). Target coordinates are entered in the mission computer and the aircraft descends for low-altitude ingress (~100 feet for day missions, ~500 ft for night). At pop-up, the target must be reacquired. In Figure 2a pop-up occurs at stand-off ranges of about 50,000 feet, allowing more time for target acquisition and guided weapon delivery but also increasing the period of vulnerability to air defense sites (fixed or mobile). In Figure 2b, pop-up is delayed until about 10,000 feet target range, allowing a minimum of time for acquisition and strike, but also minimizing exposure time to air defense.

The air-to-ground mission phase profile shown in Figure 2a might be represented by an F-18 equipped with a high performance FLIR (compatible with target detection ranges in excess of 50,000 feet), a laser spot tracker for cuing in a hunter-killer mode, a laser designator for designation of targets for laser-guided bombs or missiles (Bulldog or Maverick) or hand-off to another strike aircraft, and a laser ranger for computation of accurate weapon release conditions. This kind of sensor suite can be described as "TRAM-like". The radar target acquisition and weapon release modes would be considered back-ups to the TRAM (Target Recognition/Attack Multisensor; A-6E and A-7E versions).



a. RUN-IN TO TARGET, POP-UP AT STAND-OFF RANGES

b. RUN-IN TO TARGET, POP-UP AT MINIMUM TIME EXPOSURE RANGES

Figure 2. Typical interdiction run-in to target and air-to-ground combat phases.

Pop-up at stand-off ranges (Figure 2a) could be used in attacking air defense sites. The targets would be initially detected with emitter locators; target coordinates would be entered in the INS/computer prior to descent and run-in; and pop-up, reacquisition and weapon delivery would be accomplished at 6 to 7 n. mi.

A variation of this maneuver is being explored in the Improved Wild Weasel program, using IIR Maverick missiles. The corresponding mission profile is shown in Figure 2b. The F-18 pops up as before according to the emitter locator data, but at the last possible moment. The F-18 then reacquires the target and hands-off to a launch and leave missile such as a TV or IIR Maverick, followed by pop down and egress. The target reacquisition may be assisted by use of the FLIR in the sensor suite. In this mode of last-minute pop-up, the laser spot tracker and laser designator/ranger have lesser importance, compared to the stand-off pop-up case.

The utilization of the profiles described in Figure 2 depend on the weapon and flight mix. The run-in to target and air-to-ground combat mission phases described above hold the greatest potential for simultaneous sensor presentation techniques since they require that:

1. A mix of defensive and offensive sensors be utilized, and
2. The sensor data be acquired, processed and displayed in the most meaningful and quickly interpretable manner to achieve mission success.

2.2 AVIONICS SUITE

The F-18 aircraft will carry a sophisticated avionics suite, as illustrated in Figure 3, including navigation systems, communications and identification systems, electronic warfare systems, an airborne weapon control system, and a set of displays and controls. Centered on two central digital computers, the avionics equipment is tied with a multiplex system providing flexibility for altering or adding new equipment. Key elements of interest for this study are the interdiction mission armament, the aircraft sensors and missile sensors, and the displays which provide most of the combat management information to the pilot.

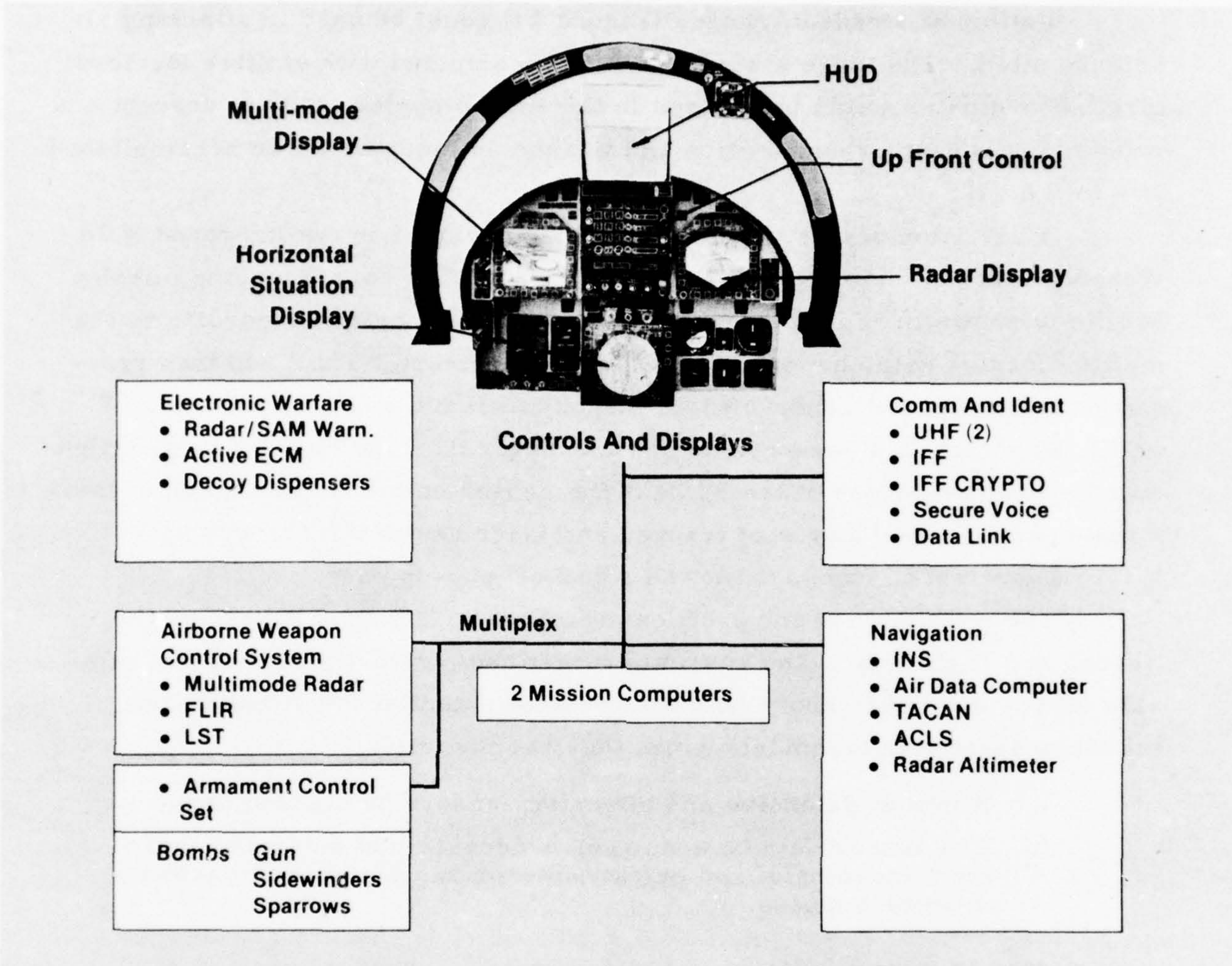


Figure 3. F-18 avionics suite.

2.2.1 Ordnance

Air-to-air weapons and SAMs are considered to be the major threat for the air superiority mission. Ground-to-air AAA and SA-6/7/8/9 are considered the major threat to the air-to-ground strike missions.

The postulated ordnance for the F-18 includes: AIM-7F, AIM-9L, Mk 82, Mk 83, Mk 84, Bulldog, Maverick (AGM-65A, B, C, D), Walleye (TV and IR), HARM, CBU, FAE II, rockets, fire bombs and 20 mm gun. The armament is carried on nine store stations, as shown in Figure 4, for a total capability of nearly 14,000 pounds. The interdiction mission is shown with the carriage of two Sidewinders (close-in missiles on each wing tip for low drag and optimum sensor look angle), an M61, 20 mm cannon (mounted

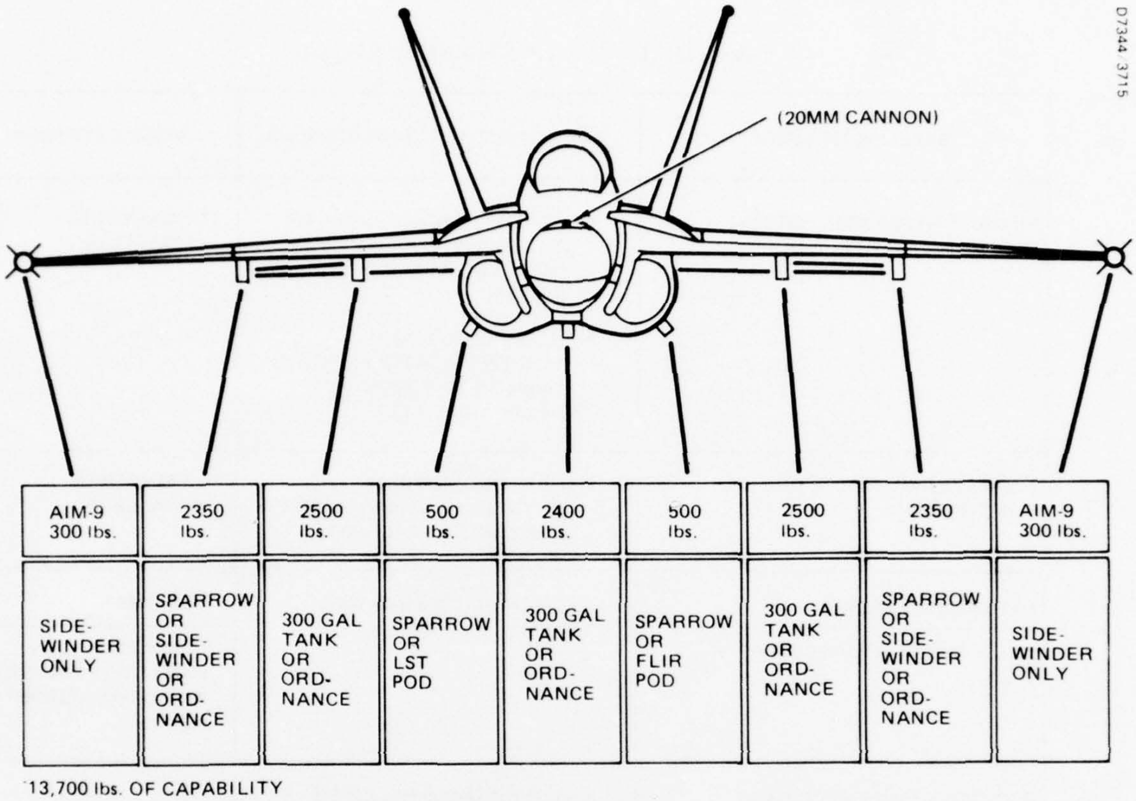


Figure 4. Multimission armament.

in the fuselage ahead of the cockpit), 4 Mk-83s (2 on each outboard wing station), three 300-gallon tanks, and a FLIR and laser spot tracker (LST) pod on each of the lower "corners" of the fuselage. The F-18 has full capability for the complete range of conventional, laser/EO-guided and anti-radiation weapons.

2.2.2 Sensor Suite

The sensors postulated for the F-18 aircraft are listed in Table 1 including the most probable baseline sensors, the most desirable additional sensors or sensor modes for improved capability in the air-to-ground combat role, and the most probable sensors associated with smart bombs and missiles. All of these sensors (excluding A-A radar) could potentially be utilized in the preliminary target acquisition, run-in to target and air-to-ground combat phases of the interdiction mission.

TABLE I. F-18 SENSOR SUITE

'BASELINE' SENSORS	'DESIRABLE' OPTIONAL SENSORS	MISSILE SENSORS
VISUAL TARGET ACQUISITION SYSTEM (VTAS)	• DAY TV TRACKER (SIMILAR TO NAVY PAVEKNIFE OR IMPROVED WEAPON DELIVERY SYSTEM) • HIGH RESOLUTION TV IDENTIFICATION SYSTEM (*SIMILAR TO TISEO*), LASER-AIDED LLLTV	TV MAVERICK TV WALLEYE
FLIR (SIMILAR TO A-6E OR A-7E TRAM)	• HIGH RESOLUTION IR IDENTIFICATION SYSTEM, IR WARNING RECEIVER	IIR MAVERICK IR WALLEYE
LASER SPOT TRACKER	LASER-AIDED SEARCH AND TRACK (LAST) POD	TOA/DME
LASER DESIGNATOR/RANGER		LASER SEMIACTIVE (BULLDOG, MAVERICK AND LASER-GUIDED BOMBS)
RADAR WARNING RECEIVER	LASER WARNING RECEIVER	
AIR-TO-GROUND RADAR • REAL BEAM GROUND MAP • DOPPLER BEAM SHARPENED SECTOR OR PATCH • GROUND MOVING TARGET INDICATION/TRACK • FIXED TARGET TRACK • A-G RANGING • TERRAIN AVOIDANCE • SEA SURFACE MAPPING	• SYNTHETIC APERTURE RADAR STRIP MAP AND TELESCOPE TRACK • BEACON • TERRAIN FOLLOWING • SEABORNE MOVING TARGET MAPPING	
AIR-TO-AIR RADAR • PULSE SEARCH • VELOCITY SEARCH • RANGE WHILE SEARCH • TRACK WHILE SCAN • SINGLE TARGET TRACK • NONCOOPERATIVE TARGET RECOGNITION • AIR COMBAT MODES		SEMIACTIVE, ACTIVE RADAR, CW AND PD
DATA LINK • JOINT TACTICAL INFORMATION *DISTRIBUTION SYSTEM*		
A PRIORI SENSOR DATA		

2.2.3 Displays

The integrated display set includes:

- A head-up display (HUD) which superimposes symbology and alphanumerics on the pilot's view of the outside world, providing weapon-aiming information as well as essential navigation and primary flight instrumentation.
- Two multipurpose display indicators (MDI), one on the right and one on the left, to provide a radar display and a multimode display for control of armament, mode selection, built-in-test, and display of EO weapon sensors,
- A moving map display with the EW information presented over the map, and
- An up-front control panel between the two MDIs for selection and control of communication and identification.

2.3 AVIONICS INTERFACE FOR AIR-TO-GROUND COMBAT

Based on the interdiction mission defined in Section 2.1 and the F-18 avionics suite described in Section 2.2, the interfacing of key avionics utilized in the target acquisition and weapon delivery phases can be examined. The avionics functional block diagram is illustrated in Figure 5, configured from the baseline F-18 sensor suite listed in Table 1, and compatible with the system requirements of Figure 2. This configuration includes:

- A multimode radar system such as the F-18 radar,
- A TRAM-like system including the FLIR and laser designator/ranger/spot tracker,
- Weapon system including the missile imaging sensors,
- Laser/radar warning receivers, IFF threat identification, and data-linked threat data,
- Navigation systems including INS, TACAN, and GPS,
- General processing equipment such as the central processing unit (CPU) and the weapon release computer system (WRCS),
- Dedicated computers including the air data computer, processors associated with the TRAM-like system and the radar system for video processing and coordinate transform, and the video correlation hand-off and boresight unit which interfaces the TRAM and missile imaging sensors.

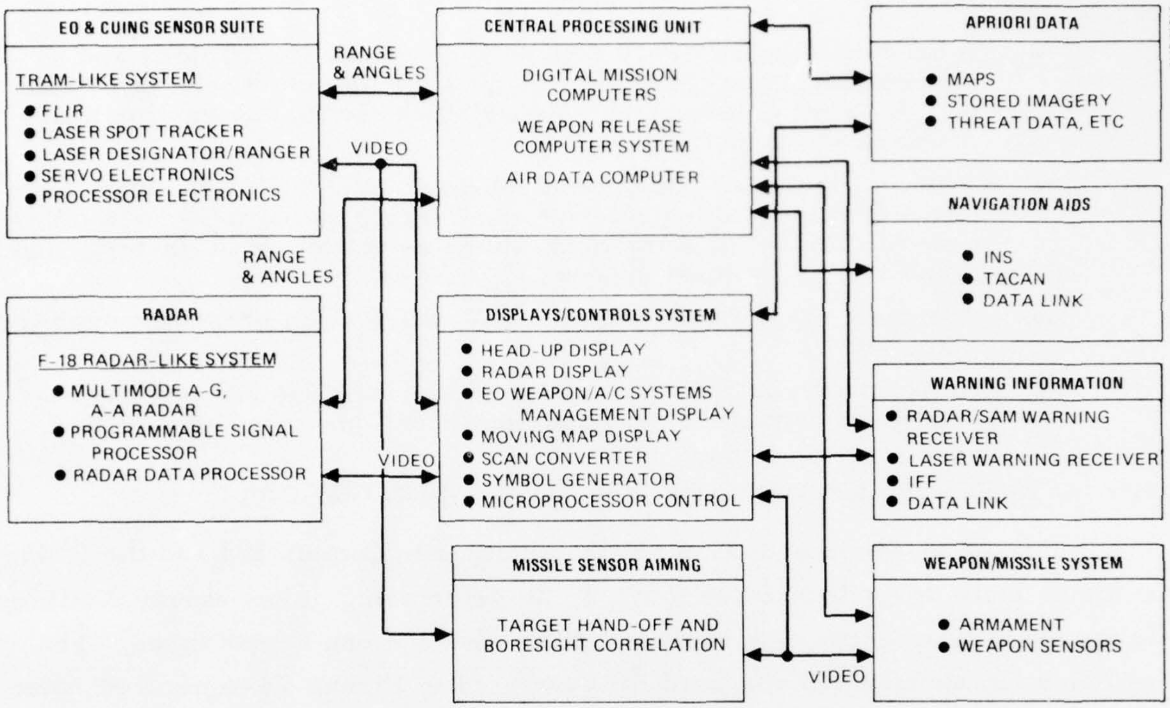
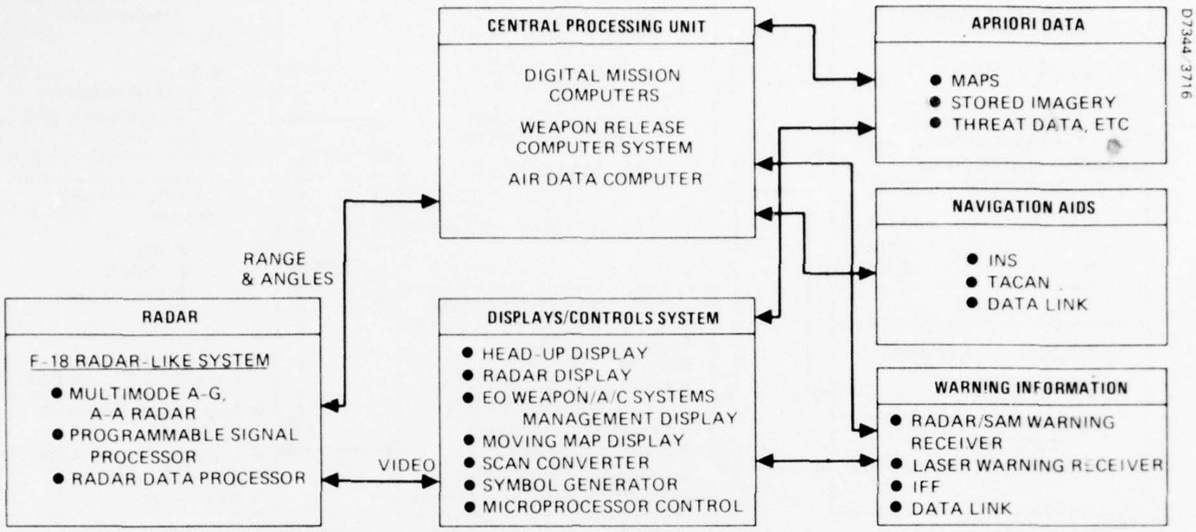


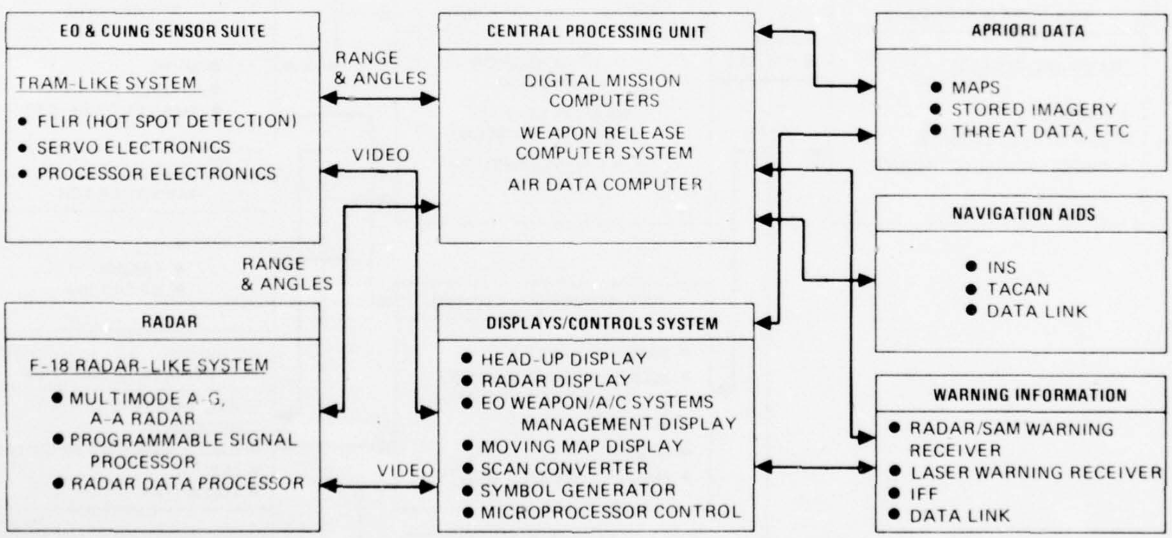
Figure 5. Functional block diagram of general interdiction mission avionics.

Figure 6 shows the utilization of the various avionics subsystems during cruise-in (navigation), during preliminary target acquisition, during target reacquisition at a stand-off range pop-up, and during a minimum range pop-up. In all these cases, it is seen that a multiplicity of sensors are sampling various sets of the navigation, target acquisition and weapon release data. Furthermore, these various sets of data are being utilized in some manner by all the mission displays.

Utilization of the various sets of data is essential for accomplishing the mission. The ability to sample multi-attributes of a target was demonstrated in Viet Nam to be a definite asset for rapid, high probability of target acquisition (private communication, Col. J. Krause, USAF). Yet, human factors studies (see literature survey, Appendix A) have shown that an observer's performance is degraded, especially with respect to time, if an observer must acquire and assimilate the multi-attribute data from several displays. These factors bring us to the key issue of this study, to examine

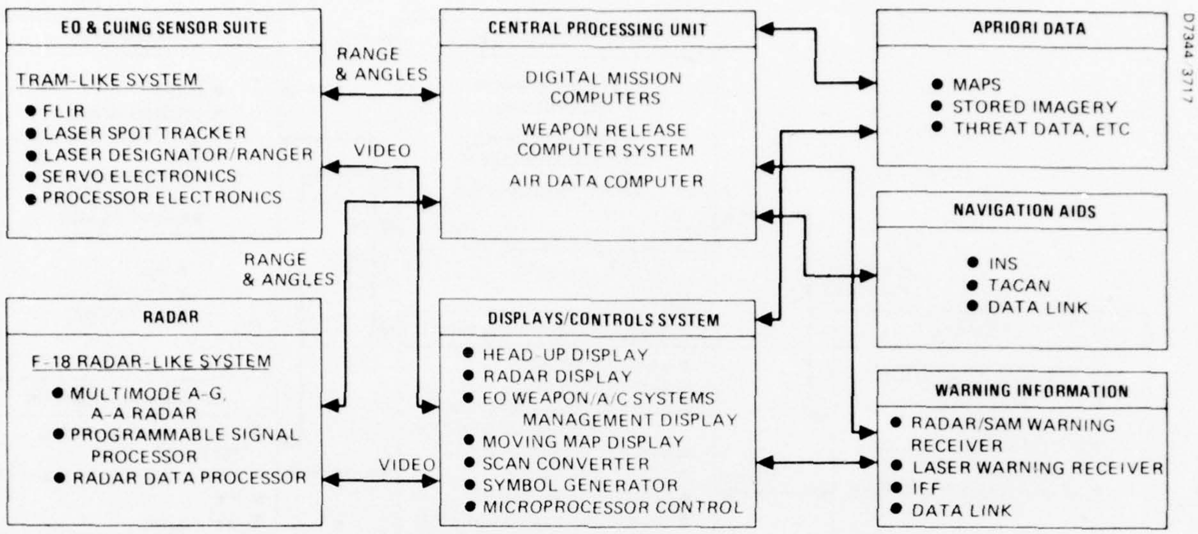


a. CRUISE-IN (NAVIGATION)

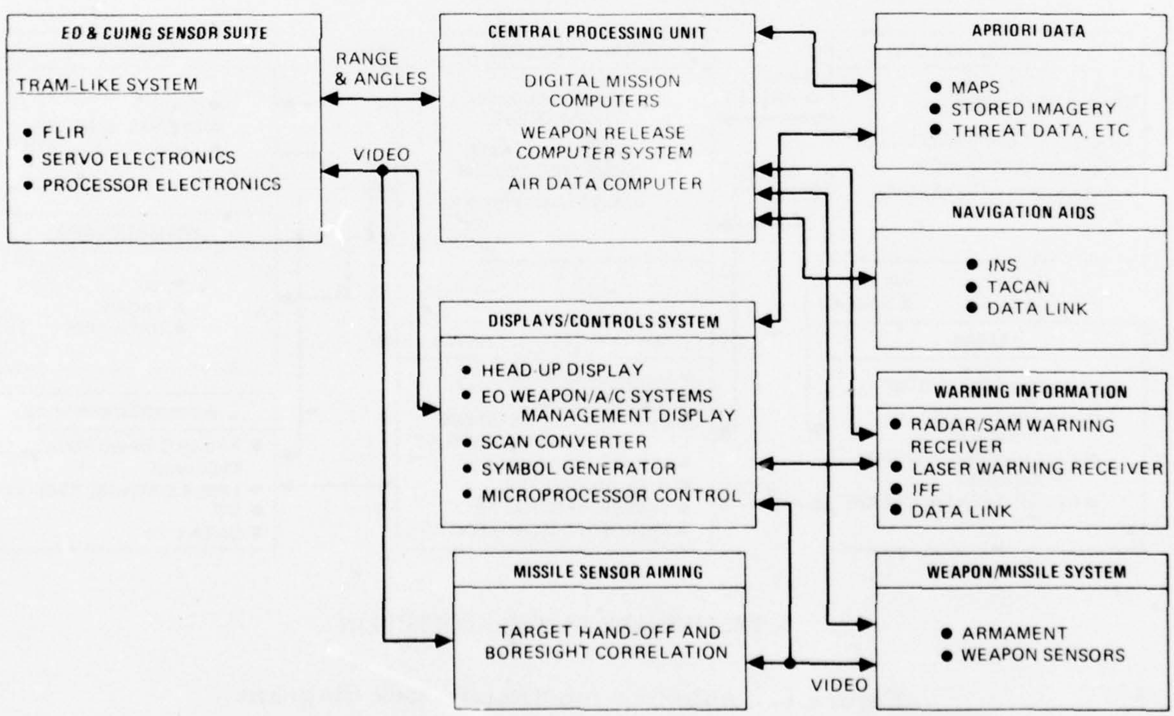


b. PRELIMINARY TARGET ACQUISITION

Figure 6. Avionics functional block diagram per mission phase. (Sheet 1 of 2)



c. STAND-OFF RANGE POP-UP TARGET ACQUISITION



d. MINIMUM RANGE POP-UP TARGET ACQUISITION

Figure 6. Avionics functional block diagram per mission phase. (Sheet 2 of 2)

techniques of simultaneously presenting the various essential sets of data on a single display in order to obtain the target acquisition improvement associated with multi-attributes while avoiding an increase in operator task loading.

This issue is addressed here in the following manner. In each of the mission phases, a fundamental sensor or data set is selected, and all other simultaneously obtained sensor information or data are considered supplementary. In practice, this means that the fundamental sensor information or data set will be displayed on its usual monitor, and the supplementary data will be overlayed as raw, processed, or symbolized data. The fundamental data set may sometimes be radar (Figure 6 a and b), and sometimes EO (Figure 6 b and c). Thus, all F-18 video displays will have a role in displaying the fundamental sensor data and its supplementary overlay. Consistent with the F-18 design and controls/displays layout, several displays are retained in this analysis. However, it is also possible to consider a single, multipurpose optimized display after defining the requirements, as discussed further in Section 4.0.

In the following sections, the particular capabilities of the baseline and desirable sensors in the F-18 avionics suite are discussed. This discussion allows the fundamental data sets to be defined for each critical mission phase. Once this is accomplished, the optimal methods of presenting the fundamental or primary data and the supplementary data are then addressed. The resulting candidate simultaneous sensor presentations which appear most promising are defined, accompanied by representative simulated imagery. The simulated simultaneous presentations allow a preliminary assessment to be made of the utility of the combined sensors or data sets to the pilot.

3.0 METHODOLOGY FOR SELECTING MULTISENSOR CANDIDATES

To evaluate the potential utility and practicality of multisensor fusion on a single display, the following framework was established as described in Section 2.0:

1. An interdiction mission for the F-18 aircraft was selected in which target acquisition time, operator task loading, and aircraft survivability are critical factors.
2. The F-18 avionics suite was defined including the baseline sensor suite, optional sensors, and missile sensors.
3. The present interfacing of the avionics elements to provide the pilot of a single seat A/C with the sensor information needed for air-to-ground combat was examined.

This section describes the methodology by which multisensor candidates for the interdiction mission were selected from the F-18 sensor suite for simultaneous presentation on a single display. In all cases, the goal was to ease the operator's task load or to increase the probability of successful task performance in shorter time or at longer range. The resultant baseline sensor candidates are summarized in Table 2 as a function of mission phase.

The selection procedure was sequenced as follows:

1. The general capabilities of the baseline and optional sensors in the F-18 avionics suite were examined.
2. The types of a priori or data-linked information that may be available for display throughout the interdiction mission were determined.
3. The operator tasks associated with the information provided by each sensor or data source were defined.
4. Based on operator tasks per mission phase, information requirements, and sensor capabilities, those sensors or data sources which could be utilized during each phase of the interdiction mission were determined.
5. Sensors which could be used within the target acquisition phases of the interdiction mission were further subdivided according to type of target – fixed or mobile targets, moving targets, and emitters.

As a result of these five considerations, several logical groupings of sensors emerge for possible combination, based on similarities in

TABLE 2. SENSOR CANDIDATES FOR COMBINATION AS A FUNCTION OF MISSION PHASE

SENSOR \ MISSION PHASE	CRUISE NAVIGATION	PRELIM TARGET ACQUISITION	RUN-IN TO TARGET	TARGET DETECTION	TARGET IDENTIFI-CATION WEAPON DELIVERY	DAMAGE ASSESSMENT
TV *					X	
FLIR		X	X	X	X	X
LASER DESIG/RANGER				X	X	
LASER SPOT TRACKER				X	X	
RADAR GROUND MAP	X	X		X	X	
GMTI		X		X		
GMTT, FTT	X				X	
BEACON **	X					
TERRAIN FOLLOWING/ AVOIDANCE **			X			
RADAR WARNING RECEIVER	X	X	X	X	X	X
AIR-TO-AIR RADAR	X					
DATA LINK INFO	X	X				
STORED MAPS, IMAGERY	X	X		X	X	X

* MISSILE SEEKER

** HIGHLY DESIRABLE OPTIONS INCLUDED WITH BASELINE AS DEFINED IN TABLE 3-1

operational range as well as the existence of multiple complementary signatures for a single target in diverse regions of the electromagnetic spectrum.

3.1 SENSOR CAPABILITIES

A baseline sensor suite for the F-18 aircraft was identified in Section 2.0, as well as several desirable but optional sensors. To determine which of these sensors are compatible for simultaneous data

presentation on a single display, the operational characteristics and capabilities of each sensor have been examined in terms of:

- Type of information which the sensor provides,
- Typical format in which that information is displayed to the operator,
- Field of regard of the sensor, i.e., total angular coverage within which the sensor field of view can be positioned (for example, gimbal limits of the sensor platform),
- Field of view of the sensor, i.e., angular coverage of the sensor within one update or frame time,
- Sensor resolution,
- Update rate, i.e., time during which information is acquired from full field of view and processed for display,
- Dynamic range, i.e., ratio of maximum to minimum signal which can be detected or processed by the sensor under normal operating conditions,
- Operational range, i.e., range between target and sensor at which specific operator tasks can be accomplished via the sensor display such as target detection, recognition, etc., or specific sensor/processor tasks can be accomplished such as A-G GMTI or A-A Track-While-Scan, etc.

Characteristics of the information provided by the F-18 baseline and optional sensors are summarized in this section. Typical values of key sensor parameters are listed in Table 3.

3.1.1 Television (TV)

Airborne TV sensors have been developed for:

1. Daytime long range target identification, precision tracking (using gated video trackers), and missile guidance; and
2. Low light level observation of terrain for purposes of flight control, general orientation, target detection, acquisition, tracking, identification and weapon delivery.

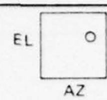
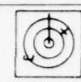
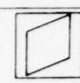
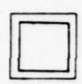
TV sensors detect luminance contrast within a scene and provide azimuth-elevation video imagery. At low light levels, TV performance is severely limited compared to the infrared sensor. The low light level TV (LLLTV) with image intensifier stage was developed for nighttime operation and functions down to about 1/4 moon illumination. Below this level, an illuminator-aided TV has been explored to improve nighttime performance by using pulsed lasers for illumination of the object space.

TABLE 3. SENSOR CHARACTERISTICS

SENSOR	DISPLAY DATA	DISPLAY FORMAT	FIELD OF REGARD	FIELD OF VIEW	RESOLUTION	UPDATE RATE	OPERATIONAL RANGE
DAY TV WITH EO TRACKER	TV IMAGERY	525 TO 1024 LINE TV 3:4 ASPECT RATIO EL AZ	$\pm 45^{o}$ AZ 0 TO -135^{o} EL CAN BE LOWER HEMISPHERE	WFOV: $20^{o} \times 20^{o}$ MFOV: $5^{o} \times 5^{o}$ NFOV: $1^{o} \times 1^{o}$	300 TO 800 TV LINES	$\frac{1}{30}$ SEC	NATO STANDARD TARGET ACQUISITION AT 10 NMI
HIGH RESOLUTION TV	TV IMAGERY	525 TO 1024 LINE TV 3:4 ASPECT RATIO EL AZ	$\pm 15^{o}$ AZ $\pm 15^{o}$ EL CAN BE HEMISPHERE	WFOV: $2^{o} \times 2^{o}$ NFOV: $.5^{o} \times .5^{o}$	300 TO 800 TV LINES	$\frac{1}{30}$ SEC	<10 NMI
MISSILE TV SIMILAR TO MAVERICK WALLEYE CONDOR	TV IMAGERY	525 LINE TV 1:1 ASPECT RATIO EL AZ	$\pm 45^{o}$ AZ $+15^{o}$ TO -45^{o} EL APPROX	$5^{o} \times 5^{o}$	300 TV LINES	$\frac{1}{30}$ SEC	<10 NMI FOR LAUNCH AND LEAVE; >10 NMI WITH DATA LINK
LLLTV	TV IMAGERY	525 TO 1024 LINE TV 3:4 ASPECT RATIO EL AZ	$\pm 45^{o}$ AZ $+5^{o}$ TO -45^{o} EL CAN BE LOWER HEMISPHERE	WFOV: $20^{o} \times 20^{o}$ MFOV: $5^{o} \times 5^{o}$ NFOV: $1^{o} \times 1^{o}$	300 TO 800 TV LINES; < 1/4 MOON 100 TO 200 LINES	$\frac{1}{30}$ SEC	<10 NMI
FLIR	8 TO 11 μM IMAGERY	525 TO 875 LINE TV 1:1, 3:4 ASPECT RATIO EL AZ	$\pm 45^{o}$ AZ $+5^{o}$ TO -35^{o} EL CAN BE LOWER HEMISPHERE	WFOV: $12^{o} \times 12^{o}$ MFOV: $3^{o} \times 3^{o}$ NFOV: $1.5^{o} \times 1.5^{o}$	<1 MRAD	$\frac{1}{30}$ SEC	<10 NMI
MISSILE THERMAL IMAGING SIMILAR TO IIR MAVERICK	8 TO 11 μM IMAGERY	525 LINE TV 1:1 ASPECT RATIO EL AZ	$\pm 45^{o}$ AZ $+15^{o}$ TO -45^{o} EL	WFOV: $3^{o} \times 3^{o}$ NFOV: $1.5^{o} \times 1.5^{o}$	<1 MRAD	$\frac{1}{30}$ SEC	<10 NMI
IR SEARCH AND TRACK	INITIAL: HIT/MISS VIDEO WARNING FINAL: 3 TO 5 μM IMAGERY	AZ vs EL 525 TO 875 LINE TV WITH SCAN CONVERTER EL AZ	$\pm 60^{o}$ AZ $\pm 90^{o}$ EL	$<0.1^{o} \times 0.1^{o}$	<1 MRAD	4 TO 5 SEC	DETECT MIL POWER A/C AT <15 NMI (NOSE) >60 NMI (TAIL)
IR TAIL WARNING	HIT/MISS VIDEO; BEARING OF MISSILES AND INTERCEPTOR A/C	SYMBOL ON AZ-EL DISPLAY (OR WARNING LIGHT AND A/N READOUT) EL AZ	$\pm 90^{o}$ AZ $\pm 30^{o}$ EL	$0.5^{o} \times 2.5^{o}$	1 MRAD	3 SEC	DETECT MISSILE AT <5 NMI (NOSE) >20 NMI (TAIL)

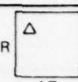
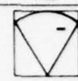
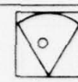
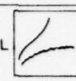
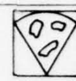
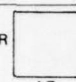
(Continued next page)

(Table 3, continued)

SENSOR	DISPLAY DATA	DISPLAY FORMAT	FIELD OF REGARD	FIELD OF VIEW	RESOLUTION	UDPATE RATE	OPERATIONAL RANGE
LASER SPOT TRACKER	DIRECTION OF LINE OF SIGHT	SYMBOL ON AZ-EL DISPLAY, HUD, OR GUNSIGHT 	IF COLOCATED, SAME AS FLIR OR TV; IF SELF-CONTAINED, $\pm 45^{o}$ AZ, $+15$ TO -45^{o} EL	$\sim 5^{o} \times 5^{o}$	N. A.	1 SEC	>10 NMI (GFAC - DESIGNATED)
WARNING RECEIVER RADAR	HIT/MISS VIDEO; BEARING AND IDENTIFICATION OF EMITTER/ ILLUMINATOR	AZ vs LETHAL RANGE RINGS, A/N SYMBOLS TO IDENTIFY THREAT TYPE AND PRIORITY THREAT SYMBOL 	360^{o} AZ 0 TO -70^{o} EL	360^{o} AZ 70^{o} EL		<1 MSEC	>50 NMI
LASER			360^{o} AZ 170^{o} EL	360^{o} AZ 170^{o} EL		<1 MSEC	<10 NMI
AIR-TO-GROUND RADAR • REAL BEAM GROUND MAP (RBGM)	VIDEO IMAGERY (8 GRAY SHADES); CURSORS; AZ, RANGE SCALE MARKERS	PPI SECTOR R vs AZ 	$\pm 60^{o}$ AZ $\pm 5^{o}$ EL	20^{o}, 45^{o}, 90^{o}, 120^{o} AZ 3^{o} TO 10^{o} EL	3^{o}	$\frac{1}{3}$ TO 2 SEC	160 NMI
• DOPPLER BEAM SHARPENED SECTOR OR PATCH (DBS)	VIDEO IMAGERY (8 GRAY SHADES); SECTOR: CURSORS, AZ AND R MARKERS PATCH: CURSORS, AZ AND R NUMERICS	1) PPI SECTOR 2) PPI PATCH 	$\sim 50^{o}$ AZ $\pm 5^{o}$ EL	TO $\pm 15^{o}$ AZ 3^{o} TO 10^{o} EL	$<0.5^{o}$ PROCESSING DEPENDENT	$\frac{1}{2}$ TO $4\frac{1}{2}$ SEC	40 NMI
• SYNTHETIC APERTURE RADAR (SAR)	VIDEO IMAGERY (8 GRAY SHADES); CURSORS	1) SIDE-LOOKING PASSING SCENE STRIP MAP  2) TRACK TELESCOPE 	1) 1/2 TO 20 NMI RANGE WINDOW OUT TO 100 NMI 2) 1/4 TO 2 NMI RANGE WINDOW OUT TO 100 NMI	1) 10 NMI SQUARE FRAME TYP. 2) 1 NMI SQUARE FRAME TYP.	80, 20, 10, 5 FT IN BOTH RANGE AND AZ	A/C SPEED DEPENDENT	160 NMI
• GROUND MOVING TARGET INDICATION (GMTI)	TARGETS DISPLAYED AT MAX INTENSITY ON GROUND MAP VIDEO OR TARGET SYMBOLS; DESIGNATING CURSOR	RBGM PPI SECTOR OR DBS SECTOR/PATCH OR SAR STRIP MAP	90^{o} AZ 10^{o} EL	20^{o}, 45^{o}, 90^{o}, AZ 3^{o} TO 10^{o} EL	3^{o}	1/3 TO 1 1/3 SEC	40 NMI

(Continued next page)

(Table 3, concluded)

SENSOR	DISPLAY DATA	DISPLAY FORMAT		FIELD OF REGARD	FIELD OF VIEW	RESOLUTION	UPDATE RATE	OPERATIONAL RANGE
• GROUND MOVING OR FIXED TARGET TRACK (GMTT, FTT)	TRACKED TARGET SYMBOL AT TARGET RANGE AND AZ	B-SCAN R vs AZ		±70° AZ ±60° EL	20°, 45°, 90°, 120° AZ	3°	PRF	GMTT: 15 NMI FTT: 30 NMI
• BEACON (BCN)	PREVIOUS FRAME BEACON REPLIES AT FULL INTENSITY (OR SYMBOLS) OVERLAID ON RBGM	RBGM PPI SECTOR R vs AZ		±60° AZ ±5° EL	20°, 45°, 90° 120° AZ 3° TO 10° EL	3°	1/3 TO 1 1/3 SEC	80 NMI
• AIR-TO-GROUND RANGING (AGR)	TARGET SYMBOL AT MEASURED SLANT RANGE TO GROUND; NUMERICAL READ-OUT OF RANGE AND BEARING	PPI SECTOR R vs AZ		±70° AZ ±60° EL	3°	3°		10 NMI
• TERRAIN FOLLOWING (TF)	TERRAIN PROFILE; MANEUVERABLE TEMPLATE OF DESIRED ALTITUDE; WEATHER WARNING	ELEVATION vs LOG RANGE		6° AZ + 10 TO −20° EL	6° AZ +10 TO −20° EL	3°	1 SEC	10 NMI
• TERRAIN AVOIDANCE (TA)	VIDEO INTENSITY OF RETURNS ABOVE CLEARANCE PLANE, HORIZON LINE SYMBOL	PPI SECTOR R vs AZ		±35° AZ ±5° EL	±35° AZ ±5° EL	3°	1 SEC	20 NMI
AIR-TO-AIR RADAR • PULSE SEARCH • VELOCITY SEARCH • RANGE WHILE SEARCH • TRACK WHILE SCAN • SINGLE TARGET TRACK	TARGET SYMBOLS, ACQUISITION SYMBOL, AZ AND EL CARETS, FLIGHT SYMBOLOGY	B-SCAN R vs AZ VEL vs AZ		±70° AZ ±60° EL	20° TO 140° AZ SEARCH 3° TO 10° EL	3°	<5 SEC TYP. STT = PRF	MODE DEPENDENT 15 TO 100 NMI
DATA LINK	1) MISSILE SENSORS: IMAGERY 2) JTIDS: 20 SYMBOLS, 64 A/N CHARACTERS	1) 525 LINE TV 2) MISSION DEPENDENT					1) 1/30 SEC 2) 128 MESSAGES PER SEC	

TV scan standards include 525, 645, 787, 875, 945 and 1024-line rasters with 60 fields per second, 2:1 interlace and a 3:4 aspect ratio. Missile TVs (Maverick, Walleye, Condor) are 525-line square rasters and are typically lower resolution sensors with comparatively less performance than target acquisition TVs. The effective resolution of TV sensors, in general, is considerably lower than that implied by the number of raster lines. Typical resolution for 525-line rasters is about 300 lines, and 600 to 800 lines for 1024-line TVs. The effective resolution of LLLTVs varies with light level and can be as high as 300 to 800 lines under bright moonlight conditions and as low as 100 to 200 lines under very dark conditions.

As with most types of pictorial information, a wide dynamic range is preferred. For this reason, automatic contrast and brightness control are typically a part of the overall system. TV is generally most useful at close to medium target observation ranges and gives a visual impression to the observer which is most like the appearance of a direct visual scene under ordinary illumination conditions. The minimum number of discernible gray levels in the system must be approximately 10 to achieve imagery without objectionable quantization effects. TV systems are among the most visually noise-free of all the sensors available.

TV sensors in an attack aircraft are gimballed and stabilized; lower hemisphere coverage can be readily accomplished. Video tracker capability and slaving to other tracking sensors are typically included in the TV system design.

3.1.2 Forward-Looking Infrared (FLIR)

FLIR sensors detect temperature differences within a scene and provide azimuth-elevation, video imagery with shades of gray similar to TV imagery. Because of the longer wavelength and generally lower number of scan lines (typically less than 500), the resolution is not as good as TV. The system also may operate more slowly than TV, perhaps at 15 to 20 frames per second. Because of the strong infrared emissions of vehicles, machinery, etc., the dynamic range of FLIR systems must be large to accommodate these emitters as well as a relatively weak background. An important visual characteristic is that the strong emitters tend to stand out sharply as "hot spots" which may tend to bloom on a display without automatic gain control. FLIR systems are most useful at short-to-medium range, and 10 or more

gray levels are generally necessary to avoid quantization noise as with visual TV. Noise levels in the image may be somewhat higher, and scan conversion and frame storage often is required to convert the data to a TV-type format.

FLIR is particularly valuable for target acquisition and weapon delivery at night. Two or more fields of view ($\sim 20^\circ$ to 1°) are typically provided for search and precision track/identification capability.

The FLIR sensor is gimballed and stabilized, with gimbal ranges in some cases extending through a lower hemisphere coverage to permit target tracking for weapon guidance through impact. Advanced FLIRs will have automatic video tracking capability. FLIR systems which have standard 525 or 875-line TV raster operation can be used with conventional TV trackers where FLIR/TV combinations are employed.

Missile FLIRs are 525-line TV compatible, but typically have lower performance and lower effective resolution than the FLIR in the aircraft target acquisition pod.

3.1.3 IR Search and Track

These IR systems use a small number of detectors which are scanned rapidly in azimuth and elevation to detect interceptors and anti-aircraft missiles above or below the horizon. In practice, they can be positioned for nose or tail warning. The output signals are displayed as intensity-modulated cell traces in a C-scan elevation versus azimuth format and require scan conversion to be TV format compatible. High resolution detector arrays can be used such that the detected threat could be tracked and imaged for identification at closer ranges.

3.1.4 Laser Spot Tracker/Designator/Ranger

Within the interdiction mission, the laser spot tracker can be used to track a ground target being designated by an AFAC (airborne forward air controller) and to provide guidance information for aircraft strike. The aircraft can utilize its own laser designator equipment to designate a target for strike by itself or by another aircraft when equipped with laser-semiactive weapons such as laser-guided bombs. The laser ranger can be used to provide accurate range data for navigation update and for weapon delivery computations.

3.1.5 Laser/Radar Warning Receiver (L/RWR)

The RWR is in general use on military aircraft to provide detection, bearing, identification, mode of operation and prioritization of threats such as SAMs (including missile guidance activity/missile launch), AI, AAA, and ground control intercept, acquisition, and height finder radars. The LWR provides detection, direction of arrival, and signature characteristics of threat lasers. Each L/RWR threat is identified by an A/N symbol on the 360 degree azimuth-range display and can be accompanied by an audio tone warning. Hand off of the video of selected threats to other aircraft systems is provided for jamming or weapon delivery.

3.1.6 Radar

Radar modes described here are intended to allow the optimum level of air-to-ground attack and air-to-air combat for operation in a single-place, high performance aircraft. To minimize required pilot action, the radar should provide automatic mode and parameter management to the maximum practical extent with manual override. It is highly desirable that the radar feature programmable signal and radar data processing. In this manner, mode logic and waveform parameters can be refined as field experience accumulates, and radar data can be translated into useful pilot data with total software control.

Air-to-Ground

The radar's air-to-ground capability includes a complement of modes which enable the pilot to 1) navigate to a wide class of checkpoints and targets, with LORAN precision and at all penetration altitudes, and 2) to detect, acquire and track stationary and moving ground and sea targets.

- The real beam ground map (RBGM) mode provides PPI mapping of large ground areas (out to 160 nmi range and 120 degree azimuth sector) for general navigation use. PPI radar sensors have visual display characteristics much different from television. The images have little gray-level quality, and objects tend to be visible as points and edges rather than broad filled-in areas. The scanning format is polar, in azimuth and elevation, thus requiring scan conversion for display on a rectangular scanned display. The digital scan conversion system must be sufficiently flexible to accommodate various ranges and sectors of the polar scan for conversion to rectangular format. The radar also has a large dynamic range, and "glints" from strong targets in a low-detail background are common. Noise in the form of clutter and object scintillation is also common.

- Doppler beam sharpening (DBS) provides a higher azimuth resolution ground map with reduced range (40 nmi) and azimuth coverage and increased processing time. Typically, the radar is initially in a RBGM mode and the pilot designates a point of interest with a cursor. The expanded DBS sector, 45 degrees azimuth coverage and up to 20 nmi mapped range interval, then appears centered in range and azimuth about the designated position. Designation of a point within this sector results in a further expansion called the DBS patch mode. A typical DBS patch is 4 x 4 nmi at 20 nmi range, centered in range and azimuth about the designated position. The map formed from the previous scan is displayed until the present scan is complete resulting in sequential snapshots.

- In the side-looking synthetic aperture radar (SAR) mode, the antenna is positioned at a fixed angle to the side of the aircraft and the forward motion of the aircraft provides the azimuth scan. Synthetic array processing provides very high resolution strip maps in range "windows" varying from 1/2 to 20 nmi which may be positioned along the range sweep from near 0 to over 150 nmi. A further refinement is the tracking telescope mode which provides discrete frames of synthetically processed radar video around a designated ground point. SAR images tend to have many "glints" due to reflections from points, corners and edges of man-made objects, resulting in an "outlining" or edge enhancing effect. The edge enhanced nature of SAR pictures may be extremely useful for frame superposition. SAR pictures tend to have a large dynamic range; thus some type of dynamic range compression or stretching is often useful before presentation to a human observer. The system operates at several hundred scan lines, but the frame rate is very slow (can be one or more seconds per frame) due to the complicated processing. The SAR images are useful primarily at long to medium ranges, and scan conversion is generally necessary for simultaneous display with other sensors. Frame storage is also required due to the relatively slow repetition rate of the new frames.

- Detection, acquisition and tracking of both fixed and moving ground targets is provided. Ground moving target indication (GMTI) symbology can be overlaid on the video from each of the ground map modes — RBGM, DBS or SAR. Ground moving target track (GMTT) and fixed target track (FTT) are displayed as symbols positioned at the target range and azimuth on a B-scan format.

- The beacon mode allows for detection of ground-based beacons and the display of appropriate symbology overlaid on ground map video.

- Air-to-ground ranging provides slant range to the ground along the antenna boresight line for discrete hard targets or diffuse terrain, and may be precisely pointed to aid in A-G weapon delivery.

- In the terrain following (TF) mode, the radar provides data to generate an elevation versus range display in the forward direction. This elevation profile of the terrain ahead of the aircraft, combined with a safe maneuver template overlaid on the display, allows the aircraft to be safely flown at low altitudes.
- The terrain avoidance (TA) mode is generally used in low altitude flight to determine optimal horizontal maneuvers such that exposure to detection, tracking and countermeasures can be minimized. Typically, the video is level sliced such that only terrain or man-made objects protruding above the selected clearance plane are displayed.
- A C-scan azimuth versus elevation radar mode could also be incorporated in the F-18 radar. Radar returns could be processed such that returns within a discrete range interval would be displayed as a single contour. Coded shading of these contours would result in a terrain clearance display.

Air-to-Air

If the F-18 is attacked by an interceptor during an interdiction mission, it will utilize its "self-escort" capability provided by the large detection coverage of its sensors and the aircraft's ability to carry and effectively use the best air-to-air weapons for the particular threat environment. The threat ranges from AAA, surface-to-air missiles, and day fighters in the limited war environment, to all-weather and supersonic cruise interceptors equipped with medium-range standoff missiles in escalated conflicts. To effectively counter these threats, the radar includes several high performance air-to-air search, acquisition, and track modes.

The pulse search, velocity search, and range-while-search modes provide all-aspect detection capability of both opening and closing airborne targets for both look-up and look-down encounter conditions. The single target track mode provides tracking of a single target, maintenance of this capability in an ECM environment, and continuous wave or pulse doppler illumination for missile launch and flight. The track-while-scan mode provides simultaneous tracking and prioritization of 12 airborne targets and a display of 8. Three air combat maneuvering modes are also incorporated and optimized for short range, heads-up air-to-air engagement. Modes can be selected manually by the pilot or commanded automatically by the mission computer.

3.1.7 Microwave Radiometry (MICRAD)

The development of MICRAD sensors for passive, all-weather navigation and landing, as well as possible target acquisition, is presently receiving considerable interest. MICRAD sensors, which typically operate in atmospheric windows at 33 or 94 GHz, depend primarily on differences in emissivity to image a scene and can operate in clouds, rain, smoke and snow cover. Images are the same day or night and there are no day/night inversions or dead times. Resolution and detection ranges are strongly dependent on the S/N ratio which in turn depends on target/background contrast, system noise, integration time, and other target, antenna and receiver characteristics. Although the MICRAD sensor is limited in range and resolution, it would provide passive, all-weather ground mapping and possible air-to-air threat detection. For the air-to-ground target acquisition and navigation update tasks of interest in an interdiction mission, the development of a forward-looking MICRAD sensor capable of rapid two-dimensional scanning (a microwave equivalent of the FLIR) with narrow field of view and slewable over a wide angle could be desirable. Automatic terrain correlation navigation with MICRAD imagery has already been demonstrated using real-time in-flight digital processing.[(Ref. 1)]

3.1.8 Data Link

The types of information which will be data linked to the aircraft include the following:

- Missile sensor data which can be flight information displayed by means of symbology.
- Missile sensor imagery such as that obtained from the TV (or eventually IR) Walleye and Condor.
- JTIDS – The Joint Tactical Information Distribution System is an advanced digital communications link used to distribute real-time data to air and ground elements in tactical operations.
- GPS – The Global Positioning System presently in development will allow worldwide electronic grid navigation using satellites for increased navigation and weapon delivery accuracy.

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[1] R. P. Moore, "Microwave Radiometric All-Weather Imaging and Piloting Techniques," AGARD Conference Proceedings No. 148, Paper 8, May 1974.

3.1.9 Effect of Weather

The sensor operational ranges listed in Table 3 represent those ranges at which the specified operator task (target detection, recognition, etc.) can be accomplished during average weather conditions. Typically, this corresponds to a visibility of about 12 km. In adverse weather such as fog or rain, those ranges are reduced depending on the spectral sensitivity of the individual sensor. Figure 7 illustrates the relative attenuation of the electromagnetic spectrum produced by fog and rain as a function of wavelength in microns (or frequency in hertz). These attenuation values can be applied to 1) passive sensor systems, such as the FLIR and TV, to determine the amount by which the target's emitted thermal or reflected solar radiation will be reduced over the target-sensor range; and 2) active systems, such as radar and laser designator/ranger/spot trackers, to determine one-way or two-way range attenuation. MICRAD systems can be passive or active.

It is evident from Figure 7 that the sensor least affected by adverse weather is the radar, either in fog or rain. In the case of fog (and clouds) the TV is most severely affected due to reflection, while the FLIR is often able to "see through" patches of fog, clouds and smoke. (On a very humid day in the absence of clouds, however, the IR absorption by water vapor may reduce FLIR performance, while the TV is virtually unaffected.) Similar to the relative effects of fog on FLIR and TV performance, the 10.6 μ laser penetrates fog (and smoke) much more effectively than 1.06 μ laser radiation.

In the case of rain, FLIR and TV are similarly affected, although far less severely than by fog. MICRAD sensors, by contrast, function extremely well in fog, but can often be outperformed by FLIR or TV during rain. Note that all the sensors in Figure 7 can be used at night except for the TV, unless an intensifier stage is added or it is illumination-aided.

3.2 A PRIORI AND DATA-LINKED INFORMATION

The type of a priori (prebriefed) or data-linked information that may be displayed to the pilot was examined by considering a representative interdiction mission from planning phase through launch, enroute to target, attack, egress, and return. The key relationships of a ground control

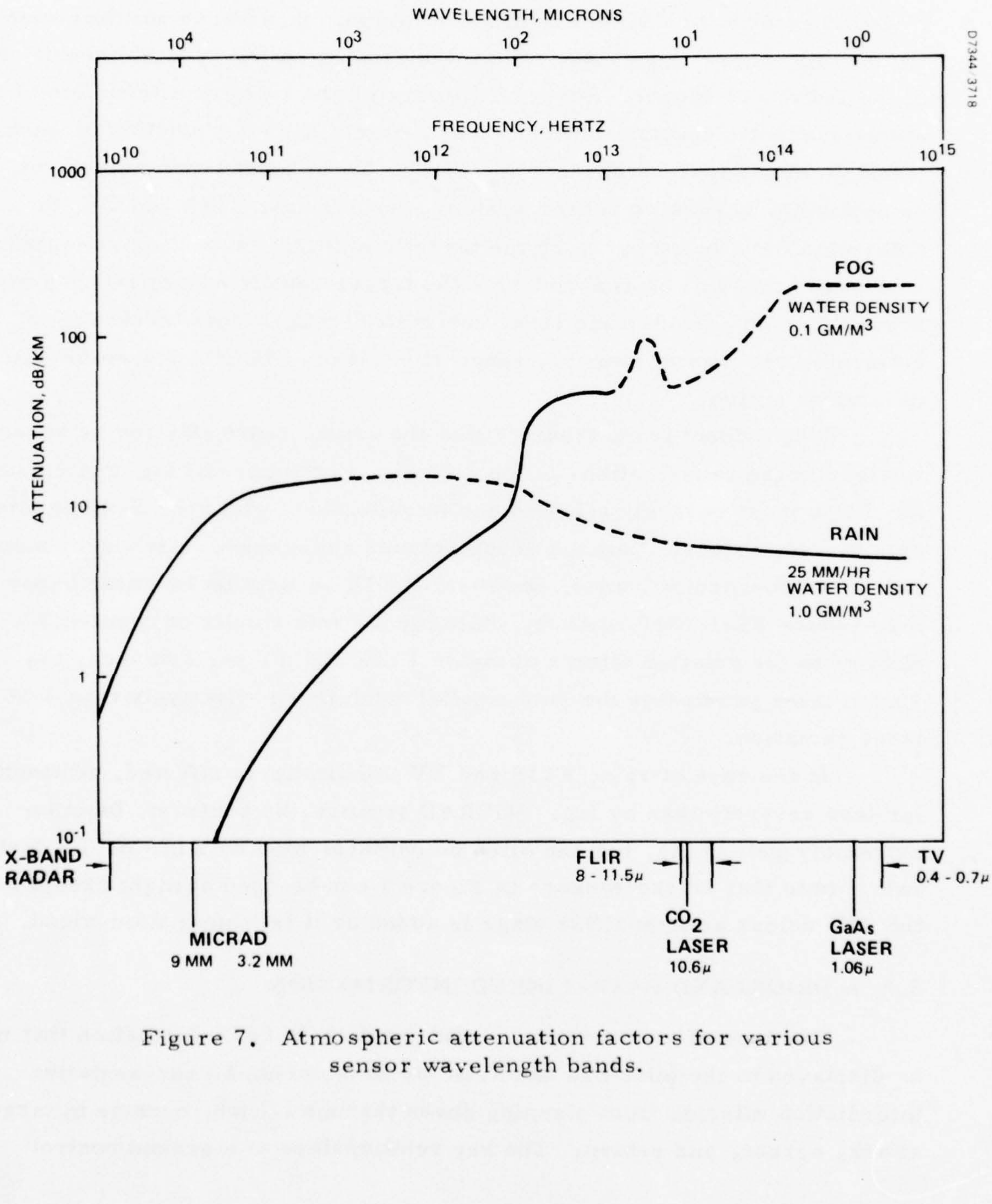


Figure 7. Atmospheric attenuation factors for various sensor wavelength bands.

station and an aircraft were examined to determine what type of information should be in the aircraft data base at launch and what information might be communicated to or from the aircraft throughout the mission.

3.2.1 A Priori Information at Take-Off

Preparing for the mission consists of anticipating the sequential use of sensors throughout the mission and selectively extracting key data for display from the master data base to assist the operator in anticipating events and recognizing deviations and new developments. In this preparation, the task may be divided into two major areas of consideration as illustrated in Figure 8:

1. The geographic swath along the route representing area covered by the primary sensors (20 to 50 nm width), and
2. The adjacent or secondary areas which contain threats and systems which may interact with the aircraft although they are out of the aircraft's sensor range.

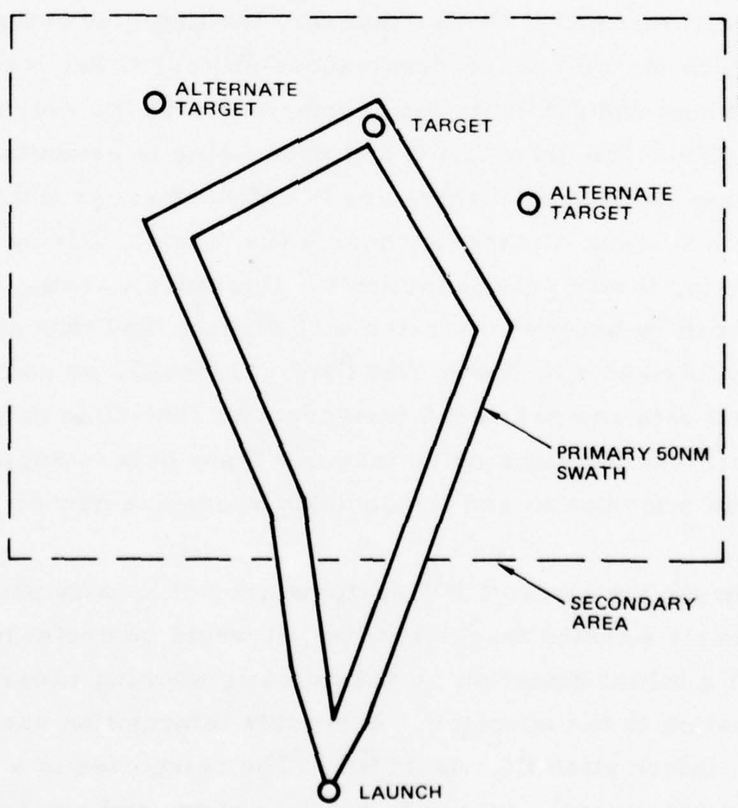


Figure 8. Primary and secondary threat areas for interdiction mission.

As the target is specified and the route and tactics are selected, the ground data base is processed to extract the map data and the defensive order of battle that will be encountered along the route. The map data can be selected for primary and alternate routes to primary and alternate targets to assist in navigation and target location/verification. The map data are stored in the aircraft data base and, in the F-18, are utilized during the mission to provide a moving map display on the horizontal situation indicator.

The order of battle includes the specific known radars and locations which the aircraft will encounter moment by moment. These threat data are stored in the aircraft data base and presented at the appropriate time on the horizontal situation or vertical situation display. Symbol coding is used to identify the threats as data from the file and not information from the aircraft sensors. This stored threat information must also be correlated with the aircraft's EW systems so that as signals are processed and displayed by the EW system, the operator may visually correlate the EW system data to the stored threat data. In like manner, the expected image of the radar and IR sensors (as well as reconnaissance photos) at key locations along the route are stored and available for comparison with the real environment.

This thorough preparation and processing is essential to the success of the mission since most targets are in defended areas and the more dense the defensive system, the more valuable the target. During the conflict in Southeast Asia, it was not uncommon for the radar warning receivers of fighter aircraft to become saturated with signals (and thus of limited value) during large strikes into North Viet Nam. However, by comparing prestored threat data and prestored imagery with real-time data, the pilot may verify threat locations or he may use these data to suppress display of non-required information and thus quickly recognize new or unexpected threats.

Although the aircraft EW systems are not usually programmed to recognize early warning tracking radar, it would be useful to determine the aircraft's initial detection by enemy early warning radars and display this information to the operator. Also, this information can be entered in the tactical information file via JTIDs. The categories of a priori data obtained prior to launch, stored in the data base, and available for display to the operator throughout the mission by means of symbology, graphics and imagery are summarized in Table 4.

TABLE 4. A PRIORI DATA STORED IN DATA BASE

Cartography	Secondary Target Route Data
Location of SAM Sites	Expected Radar Target Image
Airfields	Areas of Enemy Fighter Encounters
Location of AAA Batteries	Free Zones
Initial Radar Detection Line	Restricted Flying Areas
Expected Locations of IR Sources	Location of Friendly Forces
Major Objects from Radar Imaging	Weather
Launch Range of SAM Sites	

3.2.2 Data-Linked Information In Flight

The aircraft will interact with the overall Joint Tactical Information Distribution System (JTIDS). Own aircraft position is automatically transmitted into the JTIDS network as well as new tracks from the aircraft radar and avionics systems. The operator, in turn, accesses data from the network, either surface control or other aircraft, to update his threat information, navigation system, etc. Typical information which may be communicated to the aircraft for display during the mission is listed in Table 5.

TABLE 5. DATA LINK INFORMATION (CHANGE DATA)

Alerts to Attack by Enemy Fighters	Movement of Targets
Changes to SAM/AAA Locations	Movement of Friendly Forces
Activity by SAM Site	Relocation of Recovery Point
Time and Location of Initial Radar Detection	New IR Sources
Route Changes	Update Expected IR Images
Mission Profile Changes	Update Expected Radar Images
Change to Alternate Target	Weather Changes

The JTIDS processor correlates own aircraft track against a maximum of 200 stored tracks including friendly, hostile and unknown tracks, SAM/AAA sites, way points and weather data. Typically, own aircraft position is shown as a symbol on the center of the display and up to 40 tracks can be presented up to the limits of the display. The display center can be offset to anywhere within a 650 nm radius. The operator can select either hostile SAM/AAA and hostile airbases or hostile aircraft as the highest priority. Typical JTIDS display symbology is shown in Table 6. These symbols could be placed on a clutter-free display, accompanied by an electronically generated map or overlaid on video such as a radar ground map.

3.3 USE OF SENSOR INFORMATION FOR OPERATOR TASKS

The sensors on-board the strike aircraft provide for the general functions of:

1. Threat detection,
2. Threat defense,
3. Ground target attack, and
4. Data receiving.

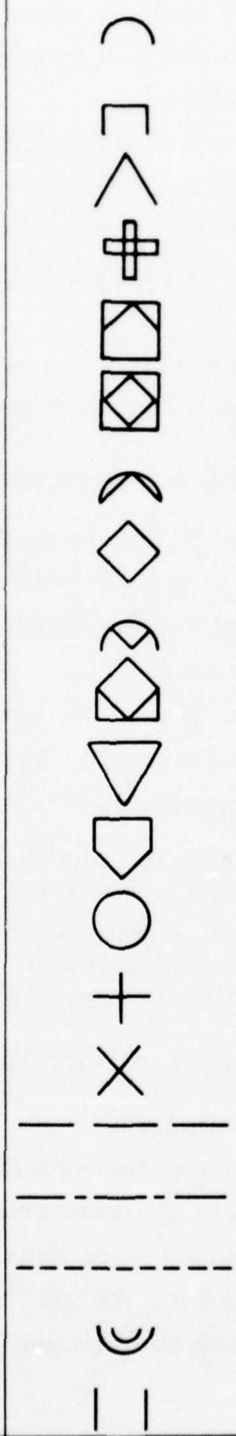
Sensors for threat detection include air-to-air radar, radar/laser warning receivers, and possibly an IR search and warning receiver. The operator's task with these sensors is principally monitoring the appropriate display, attending to aural warning from the warning receivers, and interpretation of the displayed information.

Threat defense sensors include air-to-air radar, IFF transponder/receiver, TV, and terrain following/terrain avoidance radar. Air-to-air radar would be used by the operator to lock-on and attack an airborne threat. The IFF transponder/receiver and high resolution, narrow field-of-view TV would be used to identify the threat as friendly or foe. Terrain following/terrain avoidance is used to minimize own-aircraft exposure and hence reduce the susceptibility of the strike aircraft to detection by unfriendly forces.

Ground target attack sensors include: air-to-ground radar (conventional PPI sector scan, high resolution DBS and SAR, GMTI, FTT and AGR modes), TV, FLIR and laser spot tracker. Typical operator tasks

TABLE 6. JTIDS DISPLAY SYMBOLOGY

	BASIC SYMBOL	SYMBOL WITH VELOCITY VECTOR
1. FRIENDLY AIRCRAFT		
2. UNKNOWN AIRCRAFT		
3. HOSTILE AIRCRAFT		
4. FRIENDLY AIRBASE		
5. HOSTILE AIRBASE		
6. HOSTILE BASE		
7. FRIENDLY SAM		
8. HOSTILE SAM		
9. FRIENDLY AAA		
10. HOSTILE AAA		
11. HOSTILE GROUND TRACK		
12. HOME BASE		
13. OWN SHIP		
14. DATA POINT		
15. WAY POINT		
16. FEBA		
17. SAFE AREA		
18. UNSAFE AREA		
19. DOWNED PILOT		
20. CURSOR		



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with these sensors include: parameter and/or mode selection, display brightness and contrast adjustment, terrain orientation, target area recognition, target recognition, target identification, target designation (sensor slewing or cursor designation) lock-on command, field of view or intrasensor mode change, target reacquisition across sensors or sensor modes, and commitment for weapon delivery.

Data receiving sensors include data link and beacon. These sensors are used to provide the operator with data, typically in symbolic form, on friendly, unknown, and hostile aircraft; SAM, and AAA tracks; own-base, data point, way point, FEBA, and target locations; safe and unsafe areas; and location of downed pilots.

Table 7 contains a summary of the sensor information, typical display format, and operator tasks for baseline and desirable F-18 sensors.

3.4 SENSOR UTILIZATION AS A FUNCTION OF MISSION PHASE

The possible uses of each sensor in the F-18 avionics suite were examined for various phases of the interdiction mission illustrated in Figure 9. Based on individual sensor capability and typical operator tasks associated with each sensor, Table 8 was compiled in terms of potential sensor utilization per mission phase. In addition to F-18 baseline and optional sensors, several sensors in the development stage were included.

Table 8 provides a simplified and rapid means for determining:

1. The extent to which any individual sensor could be utilized throughout an entire mission (row),
2. The multiplicity of sensors which might be utilized during a particular phase of the mission (column) and could thus be considered for simultaneous presentation on a single display.

3.5 SENSOR UTILIZATION AS A FUNCTION OF TARGET TYPE

Subsequent to determining which sensors could be used during each phase of the interdiction mission, the sensors were further subdivided according to targets of interest as summarized in Table 9. Both pre-briefed targets and targets of opportunity were considered for the interdiction mission. These included fixed (or mobile) targets, moving targets on ground, sea, or in the air, and surface and air emitters. (See glossary for acronyms.)

TABLE 7. SENSOR INFORMATION AND OPERATOR TASKS

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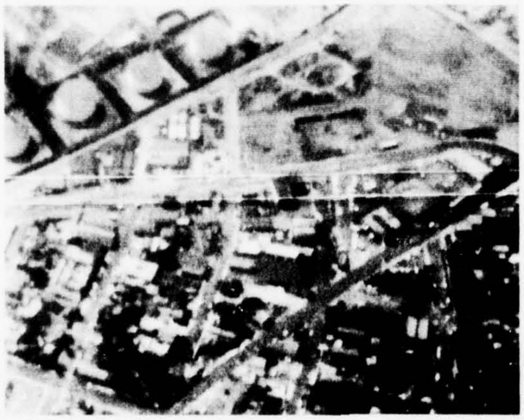
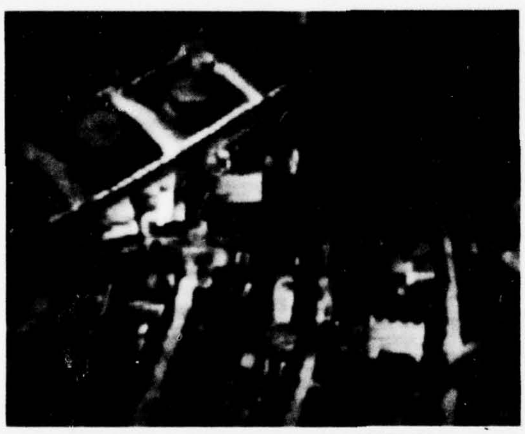
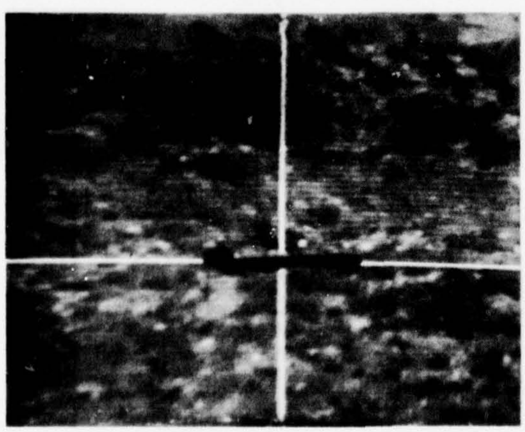
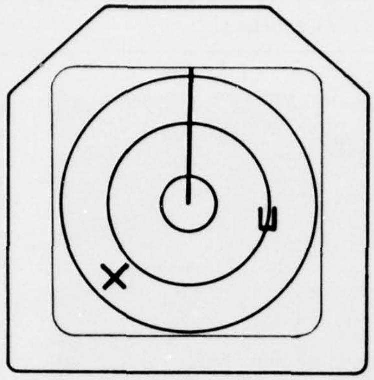
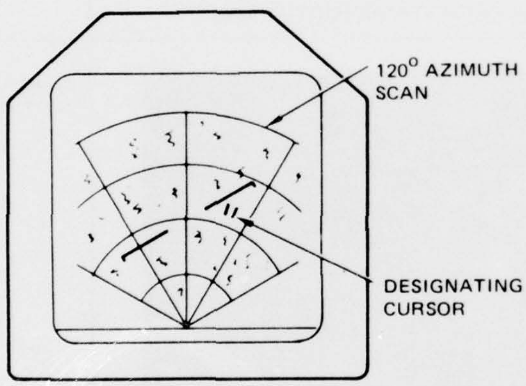
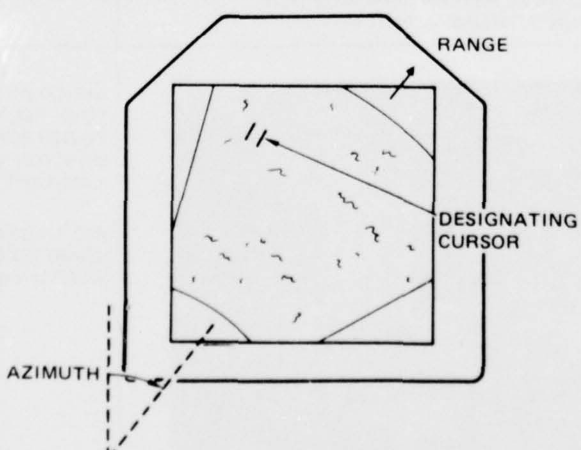
SENSOR	TYPICAL DISPLAY	OPERATOR TASKS
TV, LLLTV	 AZ VS EL PRESENTATION OF TV VIDEO	OPERATOR SEARCHES, ORIENTS HIMSELF TO GROUND SCENE; DETECTS AND RECOGNIZES GROUND OBJECTS; DESIGNATES TARGETS
FLIR	 AZ VS EL PRESENTATION OF FLIR VIDEO, THERMAL 'HOT SPOTS'	SAME AS TV, PLUS THERMAL "HOT SPOT" DETECTION
HIGH RESOLUTION TV	 TV VIDEO CUED BY RADAR OR VISUAL DETECTION:	AIR-TO-AIR: MONITOR TV VIDEO TO DETECT AIRCRAFT, LOCK-ON TO DETECTED AIRCRAFT, MONITOR VIDEO TO IDENTIFY AIRCRAFT AIR-TO-GROUND: MONITOR VIDEO TO DETECT AND IDENTIFY GROUND TARGETS

(Continued next page)

(Table 7, continued)

RADAR WARNING RECEIVER	 BEARING, RANGE AND IDENTIFICATION OF DETECTED THREATS	MONITOR RADAR WARNING RECEIVER DISPLAY, DETECT AND INTERPRET THREAT WARNING, INITIATE APPROPRIATE COUNTERMEASURES (CHAFF, FLARES, VISUAL SEARCH, EVASIVE MANEUVER, ETC)
REAL BEAM GROUND MAP RADAR	 AZ VS RANGE RADAR VIDEO	USED FOR TERRAIN ORIENTATION, NAVIGATION UPDATE, LARGE TARGET STRIKE; OPERATOR MONITORS DISPLAY FOR KNOWN PREBRIEFED OBJECTS, DESIGNATES RADAR RETURNS
DOPPLER BEAM SHARPENER SECTOR/ PATCH	 HIGH RESOLUTION AZ VS RANGE RADAR VIDEO	SAME AS REAL BEAM GROUND MAP EXCEPT IMPROVED AZIMUTH RESOLUTION PERMITS DETECTION AND DESIGNATION OF SMALLER TARGET OBJECTS AND IMPROVED DETECTION AND DESIGNATION OF LARGE TARGETS

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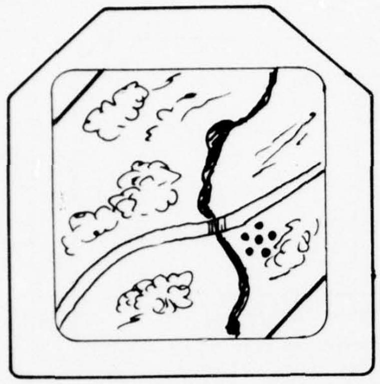
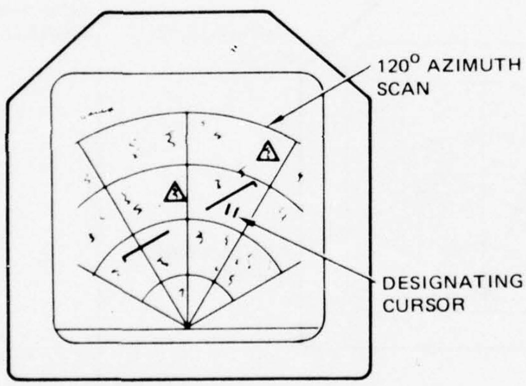
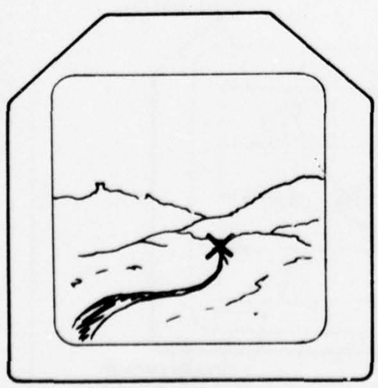
(Table 7, continued)

SYNTHETIC APERTURE RADAR STRIP MAP	 AZ VS RANGE RADAR VIDEO	SAME AS REAL BEAM GROUND MAP, EXECPT IMPROVED AZIMUTH AND RANGE RESOLUTION PERMITS DETECTION AND DESIGNATION OF TACTICAL TYPE TARGETS AND IMPROVED DETECTION AND DESIGNATION OF LARGE AND MEDIUM SIZED TARGETS
GROUND MOVING TARGET INDICATION	 AZ VS RANGE PRESENTATION OF DETECTED MOVING GROUND TARGETS INTERLEAVED WITH REAL BEAM GROUND MAP	MONITOR RADAR DISPLAY FOR RADAR DETECTED MOVING TARGETS; INTERPRET MOVING TARGET INDICATION FOR STRIKE SIGNIFICANCE, DESIGNATE GMTI RETURN, ACTIVATE AUTO TRACK
LASER DESIGNATOR/ RANGER/ SPOT TRACKER	 SYMBOL ON FLIR AZ VS EL DISPLAY OR RADAR AZ VS RANGE DISPLAY, ALSO LASER CODE, LOCK-ON INDICATION, AND RANGE TO TARGET	SET UP LASER SYSTEM, ENTER LASER CODE, DESIGNATE TARGET FOR LASING OR RANGING, OR MONITOR LASER SPOT TRACKING INDICATION, ACTIVATE SYSTEM MODES

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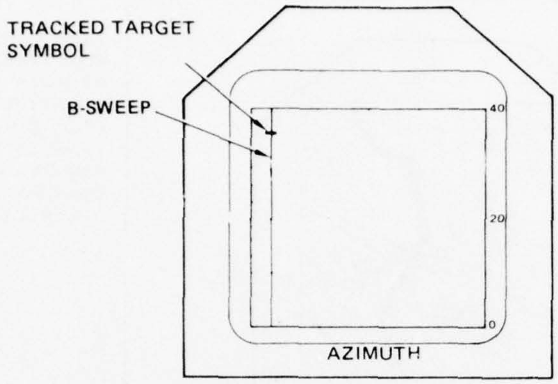
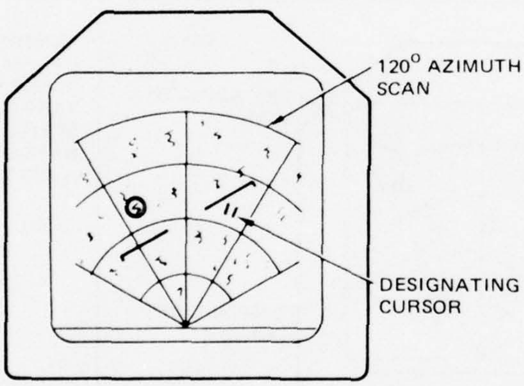
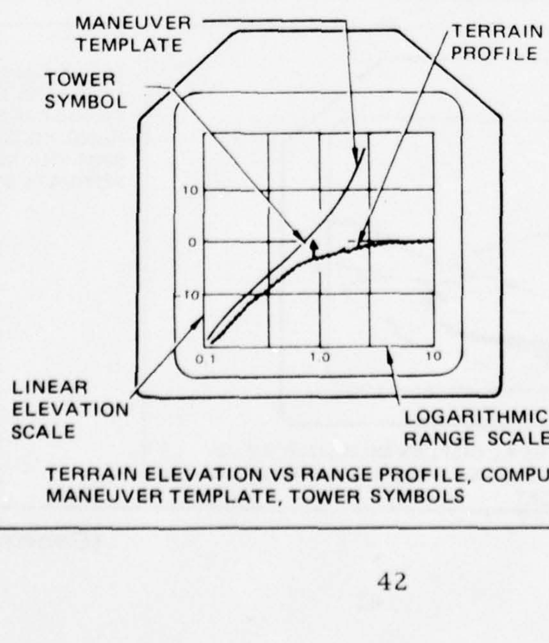
(Table 7, continued)

GROUND MOVING OR FIXED TARGET TRACK	 TRACKED TARGET SYMBOL LOCATED AT TARGET RANGE AND AZIMUTH	MONITOR AUTO TARGET TRACK, SEARCH DISPLAY FOR OTHER TARGETS
BEACON	 BEACON SYMBOL AT AZIMUTH/RANGE LOCATION OVERLAID ON REAL BEAM GROUND MAP VIDEO	DETECT BEACON SYMBOL, CONFIRM BEACON CODE, DESIGNATE BEACON SYMBOL
TERRAIN FOLLOWING	 TERRAIN ELEVATION VS RANGE PROFILE, COMPUTED MANEUVER TEMPLATE, TOWER SYMBOLS	MONITOR TERRAIN PROFILE AND MANEUVER TEMPLATE; LOOK FOR TERRAIN POINTS AND TOWER SYMBOLS ABOVE MANEUVER TAMPLATE. MANEUVER AIRCRAFT TO MAINTAIN DESIRED CLEARANCE ABOVE TERRAIN

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(Table 7, continued)

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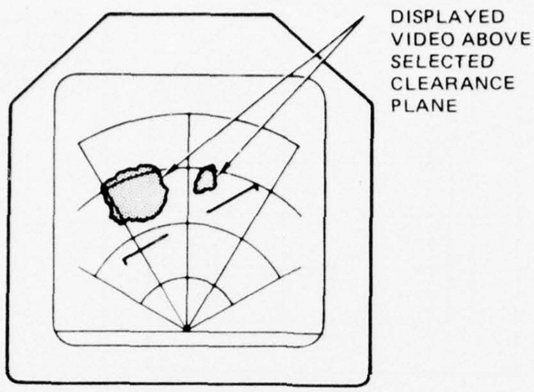
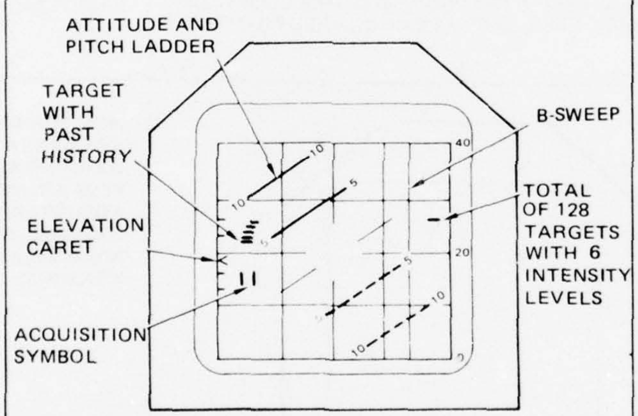
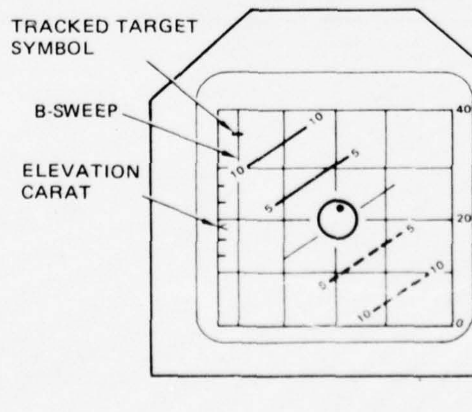
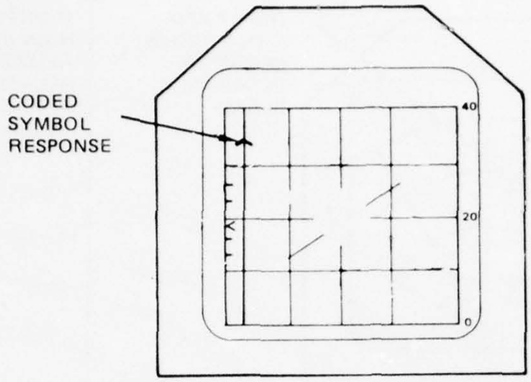
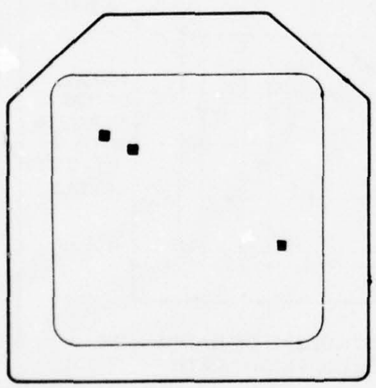
TERRAIN AVOIDANCE	 AZ VS RANGE, RANGE LINES, VIDEO OF TERRAIN ABOVE SELECTED CLEARANCE PLANE, HORIZON LINE SYMBOL	MONITOR DISPLAY FOR TERRAIN ABOVE CLEARANCE PLANE, ASSESS AIRCRAFT FLIGHT PATH RELATIVE TO TERRAIN OBSTACLES, MANEUVER AIRCRAFT TO AVOID TERRAIN OBSTACLES
AIR-TO-AIR RADAR RANGE-WHILE-SEARCH MODE	 AZ, RANGE, ELEVATION BAR OF RADAR HITS NO. OF HITS, TARGET(S) FLIGHT PATH	MONITOR RADAR DISPLAY, DETECT RADAR HITS ON DISPLAY, INTERPRET RADAR HITS REGARDING THREAT LEVEL, DESIGNATE RADAR HITS FOR LOCK-ON, MONITOR LOCK-ON, MONITOR TRACK FILES, COMMIT MISSILES FOR LAUNCH, PERFORM EVASIVE MANEUVERS
AIR-TO-AIR RADAR SINGLE TARGET TRACK MODE	 AZ, RANGE, ELEVATION BAR OF TRACKED TARGET	MONITOR RADAR DISPLAY, DETECT RADAR HITS ON DISPLAY, INTERPRET RADAR HITS REGARDING THREAT, DESIGNATE SELECTED HIT, ACTIVATE TRACK MODE, MONITOR RADAR TARGET TRACK, MONITOR FIRE CONTROL SOLUTION, FIRE WEAPON

(Continued next page)

(Table 7, concluded)

IFF TRANSPONDER/ RECEIVER	 CODE AND MODES SELECTION READOUT, RESPONSES TO INTERROGATIONS DISPLAYED ON A-A RADAR FORMAT	SET UP SYSTEM, SELECT SYSTEM MODES, CODE ENTRY, MONITOR RESPONSE TO IFF INTERROGATION
DATA LINK	ALPHANUMERIC/SYMBOLIC CODED DATA OR UNKNOWN, FRIENDLY, AND ENEMY TRACKS; AND OTHER LOCATIONS (e.g., HOME BASE, FEBA, SAFE AREAS, DOWNED PILOT, ETC)	MONITOR DISPLAYED DATA LINK INFORMATION, INTERPRET DISPLAYED INFORMATION
IR SEARCH AND WARNING	 SYMBOL ON AZ VS EL DISPLAY GIVING BEARING OF MISSILES OR INTERCEPTOR A/C	MONITOR IR WARNING RECEIVER DISPLAY (CAN HAVE WARNING AUDIO OR LIGHT PLUS A/N READOUT), DETECT AND INTERPRET THREAT WARNING, INITIATE APPROPRIATE COUNTERMEASURES

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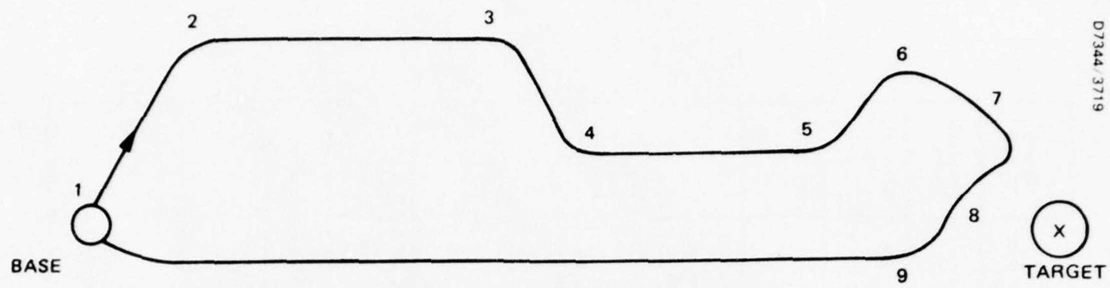

1 – 2	TAKE-OFF AND CLIMB
2 – 3	CRUISE
3	PRELIMINARY TARGET ACQUISITION
4 – 5	RUN-IN TO TARGET
5 – 6	POP-UP
6 – 7	TARGET ACQUISITION AND WEAPON RELEASE
7 – 8	POSSIBLE ASSISTANCE IN MISSILE GUIDANCE
8 – 9	POSSIBLE DAMAGE ASSESSMENT
9 – 10	RETURN TO BASE

Figure 9. Interdiction mission phases.

Key portions of the mission involving targeting were re-examined including:

1. Acquisition of pre-briefed target/threat data before take-off, and updating of target/threat information while in flight via data link
2. Preliminary target acquisition at stand-off range, before descent and ingress
3. Target acquisition after pop-up
4. Target identification and weapon release
5. Damage assessment.

Those sensors which could be utilized for the target acquisition and end game phases of the interdiction mission were obtained from the appropriate columns of Table 8 and listed in Table 9 as a function of mission phase and target type. The sensors include fixed target indication (FTI) radar such as RBGM, DBS and SAR mapping and track modes, and moving target indication (MTI) radar for both air-to-ground and air-to-air target detection and track. Over-the-horizon (OTH) information from satellite radars would be data-linked to the aircraft.

TABLE 8. SENSOR UTILIZATION PER MISSION PHASE – INTERDICTION

Sensor \ Mission Phase	Cruise 2-3	Preliminary Target Acquisition 3	Run-in to Target 4-5	Pop-Up 5	Target Detection 6	Target Recog., I.D. 6-7	Weapon Release 7	Missile Guidance 7-8	Damage Assessment 8-9	Return to Base 9-10
Day Visual - Direct View (A-A, A-G)	Natural Mode	Large Target Complexes	Override, Update	Natural Mode	(HUD)	Useful in some situations	(HUD)		Primary & Secondary Fires	Override, Update
Visual Target Acquisition System (A-G)	Not prob. except for Checkpoints		CP	Possible for IP Pop-Up Initiate	Based on Cues	Possible	Based on Cues		Would have to slew manually	CP
Day TV With E-O Tracker (Primarily A-G)	Not prob. except for CP	Possible	CP	Possible for IP Pop-Up Initiate	Based on Cues (MFOV)	NFOV with Tracker	NFOV with Tracker	Possible (LOS or Video Hand-off)	NFOV with Tracker	CP
LLLTV (Night) With E-O Tracker (A-G)	Not prob. except for CP (WFOV)	Possible	CP	Possible for IP Pop-Up Initiate	Definitely with Cue-ing (MFOV)	Definitely with Tracker (NFOV)	Definitely with Tracker (NFOV)	Same as Day TV and FLIR	Possible with Tracker (NFOV)	CP
High Res. TV Ident. System (Day) (Primarily A-A, Also A-G)	A/A Threat Ident.; CP	Possible	CP; CAP Ident. After Warning	Possible for IP Pop-Up Initiate	Possible with Cueing	Definitely with Day Tracker	Definitely with Day Tracker	Same as Day TV	Possible with Day Tracker	CP; CAP Ident. After Warning
FLIR (Day) with E-O Tracker (A-G)	Possible	Possible	Possible	Possible	Possible Esp. with Day TV	Possible Esp. with Day TV (NFOV)	Possible Esp. with Day TV (NFOV)	Possible (LOS or Video Hand-off)	Possible with Tracker (NFOV)	CP
FLIR (Night) with E-O Tracker (A-G)	Not prob. except for CP (WFOV)	Possible	CP	Possible for IP Pop-Up Initiate	Definitely with Cueing (MFOV)	Definitely with Tracker (NFOV)	Definitely with Tracker (NFOV)	Possible (LOS or Video Hand-off)	Definitely with Tracker (NFOV)	CP
High Res. IR Ident. System (Day/Night) (A-A, A-G)	A/A Threat Ident.; CP	Possible	CP; CAP Ident. After Warning	Possible for IP Pop-Up Initiate	Possible with Cueing	Definitely with Tracker	Definitely with Tracker	Same as FLIR	Possible with Tracker	CP; CAP Ident. After Warning
IR (Day/Night) Search and Warning (A-A, A-G)	← Operates continuously to detect A/A and G/A threats →									
Microwave Radiometric Sensor (Day/Night) (Primarily A-G)		Possible	CP	Possible for IP Pop-Up Initiate	Useful for some target types	Possible	Possible	Possible	Possible	
Laser Designator				Possible for IP by FAC	Hand-off by FAC	Hand-off & Comlink by FAC	Laser Semiactive self-contained or hunter-killer modes	Possible		

(Continued next page)

(Table 8, concluded)

Sensor / Mission Phase	Cruise 2-3	Preliminary Target Acquisition 3	Run-in to Target 4	Pop-Up 5	Target Detection 6	Target Recog., I. D. 6-7	Weapon Release 7	Missile Guidance 7-8	Damage Assessment 8-9	Return to Base 9-10
Laser Ranger	CP Range	IP Range	CP Range	IP Range			Valuable for computing, F/C Solns	Possible for computing Midcourse		CP Range
Laser Spot Tracker		Possible (target area hand-off with Long Knife)		Possible (GFAC or AFAC)	Hand-off from GFAC or AFAC	Hand-off from GFAC or AFAC with comlink				
Laser/Radar Warning Receiver	← Operates Continuously →									
Data Link	GPS, threat information, update a priori data	Target coordinates, threat information	Only if essential	Possible	For video handoff to missile or post-launch tgt acquisition/ aimpt. des.	Possible for post-launch target acquisition	Possible for pre-launch weapon aiming	Possible (aimpoint correction via missile video)	Possible	GPS, threat information
Air-to-Ground Radar • Real beam Ground Map	CP navigation update	Probable	Possible	IP	Possible					CP
• Doppler Beam sharpened patch	CP navigation update	Probable		IP	Possible					CP
• Doppler Beam sharpened patch	CP navigation update	Highly probable		IP	Possible	Possible			Possible	CP
• Synthetic aperture radar	CP navigation update	Highly probable	Possible	IP	Possible	Possible			Possible	CP
• Ground moving target indication		Useful			Useful					
• Ground moving target track or • Fixed target track						Useful	Useful			
• Beacon	CP navigation update	Possible	Possible for CP	Possible for IP Pop-Up Initiate	Possible cue					CP navigation update, A-A refuel
• A-G Ranging	CP navigation update		CP Range	IP Range			Target Range	Possible		CP navigation update
• Terrain following/ avoidance			Highly probable							
Air-to-Air Radar • Range-while-search • Velocity search • Pulse search • Track-while-scan • Single target track • Non-cooperative target recognition	Possible		Possible							Possible

TABLE 9. SENSOR TECHNOLOGIES FOR TARGET TYPES AND MISSION PHASES

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	FIXED TARGETS (OR MOBILE)	MOVING TARGETS			EMITTERS	
		GROUND	SEA	AIR	SURFACE	AIR
PREBRIEFED OR DATA-LINKED TARGET/THREAT INFORMATION	CARTOGRAPHY (GRID)	MTI RADAR	→	→	TEREC	→
	FTI RADAR		OTH RADAR	→	PELSS	→
	IR IMAGERY				ELS	→
	PHOTO (PTS)	UGS	USS		TASES	→
	GPS	→	→	→	→	→
	JTIDS	→	→	→	→	→
PRELIMINARY TARGET ACQUISITION (BEFORE RUN-IN TO TARGET)	FTI RADAR	MTI RADAR	→	→	L/RWR	→
	BEACON	→	→			
	FLIR HOT SPOTS	→	→	IRSS		
	TV BRIGHT SPOTS					
	LASER SPOT TRACKER					
	MULTI-SOURCE FUSION	→	→	→	→	→
TARGET ACQUISITION (AFTER POP-UP)	FTI RADAR	MTI RADAR	→		L/RWR FOLLOWED BY RF OR EO PRECISION TRACKER	→
	MICROWAVE RADIOMETRY	→	→			
	BEACON	→	→			
	LASER DESIGNATOR/SPOT TRACKER	→	→			
	FLIR	→	→	IRSS		
	TV	→	→			
	SIGNATURE	→	→	→	→	→
	MULTI-SOURCE FUSION	→	→	→	→	→
TARGET IDENTIFICATION AND WEAPON DELIVERY	FLIR	→	→			
	TV	→	→	→		
	FTI/SPOTLIGHT	MTI/SPOTLIGHT	→	NCTR	L/RWR AND SPECIAL PROCESSING	→
	LASER DESIGNATOR/RANGER/SPOT TRACKER	→	→			
	SPECIAL SIGNATURE	→	→	→	→	→
	AUTOMATIC CUE/IDENT. SYSTEMS	→	→	→	→	→
	MULTI-SOURCE FUSION	→	→	→	→	→
DAMAGE ASSESSMENT	FLIR	→	→	→	→	→
	TV	→	→	→	→	→
	FTI SPOTLIGHT	→	→			
		MTI RADAR	→	→	FTI SPOTLIGHT	MTI
			OTH RADAR	→	L/RWR	→
	SIGNATURE	→	→	→	→	→
	MULTI-SOURCE FUSION	→	→	→	→	→
		GROUND	SEA	AIR	SURFACE	AIR
	FIXED TARGETS	MOVING TARGETS			EMITTERS	

Two factors are evident in Table 9. The first is the multispectral signatures which typically characterize a target, whether based on reflectivity or emissions (intentional or unintentional), such that a target is detectable in a number of spectral regions and thus by a number of different sensors. The second is the logical grouping of those sensors according to similar operational ranges. In the following section, a sequence of multisensor simultaneous combinations based on these factors are formulated for possible utilization in the interdiction mission.

3.6 CONCLUSIONS

As a result of the interdiction mission analysis and the consideration of a multiplicity of sensors and data sources normally required for each phase of the mission, several key factors emerge:

1. Different mission phases have different information requirements, and, therefore, different real-time sensor and a priori data requirements.
2. The use of prebriefed a priori information stored in the data base and retrieved for display during various portions of the mission can be extremely important in reducing operator task load and increasing the probability of mission success.
3. During the target acquisition phases, the multi-attribute characteristics of targets permit target acquisition within a number of different spectral regions and thus by a number of different sensors. The simultaneous use of multiple sensors to acquire a particular target can increase the probability of successful target acquisition and may decrease the search time. Simultaneous multisensor capability may be especially valuable if one of the target signatures ceases (such as an emitter shutting off or a moving vehicle stopping).
4. The sensors which could be utilized simultaneously during the various mission phases fall into logical groups based on their operational range capabilities. These sensors may have differences in format, number of scan lines, field of view, resolution, and update rate, thus requiring that they be made compatible before they can be presented simultaneously.
5. Examination of the tables involving sensor utilization as a function of mission phase indicates that there is no one sensor which provides sufficient information to act as the lead sensor throughout the entire mission.

The following section attempts to 1) identify combinations of critical or primary sensors, augmenting sensors, and collateral data needed for key mission phases; and 2) estimate the potential utility of these combinations to operator performance and mission success.

4.0 CANDIDATE SIMULTANEOUS SENSOR PRESENTATIONS

In this section, several promising simultaneous presentations are selected which warrant future investigation, including combinations of a real-time sensor with other sensor data and with stored or linked collateral data. These selections are based on 1) the identification of a critical or primary sensor associated with each mission phase, and 2) the relative desirability of additional sensors and collateral data for each mission phase, as determined by estimated utility of that information to the operator and estimated criticality of that information to the mission phase.

In general, the results indicate that information sources which could be synergistically combined are range-to-target dependent. At longer ranges, these include radar ground map as the primary sensor and, as secondary sources, radar beacon and air-to-ground ranging modes, pre-briefed waypoint data, stored maps and reconnaissance imagery, a priori and linked target/threat data, and onboard warning receivers. At intermediate ranges, promising candidates include radar (primary sensor), FLIR, GMTI, A-G ranging, laser ranger/spot tracker, warning receivers, and a priori and linked target/threat data. At closer ranges, EO sensors such as FLIR (primary sensor) and TV predominate, augmented by the use of warning receivers, laser spot trackers/rangers, and possibly some types of radar data and automatic target cuing information.

In an attempt to evaluate various methods of combining the selected sensors and collateral data on a single display, a data base of available imagery was compiled. Representative static imagery was then superimposed by photographic or computer-aided CRT techniques to simulate several of the selected combinations. The resulting photographs were subjectively evaluated in terms of the relative desirability of 1) the primary sensor display only, 2) the primary sensor display adjacent to the secondary sensor or collateral data display, and 3) the secondary sensor or collateral data (or highlights of the same) overlaid on the primary sensor display.

This section describes 1) the selection of primary and secondary information for display during key mission phases, 2) the compilation of

the imagery data base, and 3) the potential use of the simultaneous presentations to the pilot as a function of mission phase (accompanied by simulated multisensor imagery synthesized from the data base where available).

Subsequent sections examine these selected simultaneous presentations in terms of processing considerations and relative complexity of implementation.

4.1 SELECTION OF SIMULTANEOUS SENSOR CANDIDATES

As concluded in Section 3.0, there appears to be no one sensor which provides sufficient information to act as the principal or lead sensor throughout the entire interdiction mission. Instead, each mission phase typically has a different primary sensor or sensor mode, and requires one or more secondary sensors or sets of supplementary information for successful task completion. Supplementary information includes a priori data and imagery stored in the aircraft data base before take-off and target/threat data linked to the aircraft in flight.

These primary sensors and secondary sensors or supplementary (collateral) information are identified in Table 10 as a function of key mission phases including cruise (navigation), preliminary target acquisition, run-in to target, and target acquisition/weapon delivery at pop-up. The relative utility to the operator of each of the secondary sources of information is estimated, as well as the relative criticality of that information to successful completion of the particular mission phase.

Based on these ratings, a number of combinations emerge which are potentially very advantageous. These recommended combinations are listed in Table 10 in terms of primary sensor imagery, secondary sensor imagery (or highlight data) and secondary collateral imagery, and a number of secondary sensors or data sources whose output can be displayed as symbology overlaid on the primary sensor video.

Note that within any single mission phase, there are significant differences among the various types of necessary or desired sensor/collateral information, i.e., one sensor or set of data does not necessarily reinforce another sensor's output. Note also the gaps which can exist when transitioning from the primary sensor of one mission phase to the primary sensor

TABLE 10. SIMULTANEOUS PRIMARY/SECONDARY INFORMATION – RELATIVE UTILITY AND CRITICALITY

Mission Phase	Primary Sensor	Secondary Sensor/Data Source	Estimated Utility to Pilot	Estimated Criticality to Mission Phase
Cruise	Radar (RBGM, DBS, SAR)		Needed for long-range navigation	High
		Beacon, A-G Ranging	Needed for navigation update	High
		Laser Ranger	Possible for navigation update, but range limited	Low
		FLIR, TV	Possible for navigation update, but range limited	Moderate
		Stored maps	Needed for navigation	High
		Stored waypoint imagery	Helpful, but typically not available	Low
		A priori waypoint info.	Necessary	High
		Data-linked update of a priori target/threat info.	Valuable, to prepare for target acquisition/defensive action	Moderate
		Warning Receivers	Necessary	Moderate
Preliminary Target Acquisition-Long Range	Radar (DBS, SAR)		Needed for long-range target acquisition	High
		GMTI	Helpful, but range and accuracy limited	Moderate
		A-G Ranging	Range limited	Moderate
		Laser Ranger	Range limited	Low
		FLIR, TV	Range limited (depending on target)	Low
		Stored maps	Helpful	Moderate
		Stored imagery of target area	Valuable, if available	High
		A priori target/threat info.	Valuable	High
		Data-linked update of a priori info.	Valuable	High
		Warning Receivers	Necessary	High
Preliminary Target Acquisition – Intermediate Range	Radar (DBS, SAR)		Needed, especially in adverse weather	High
		GMTI	Valuable for moving target cuing	High
		A-G Ranging	Helpful, but range (resolution) limited	Moderate
		Laser Ranger	Helpful, but range limited	Moderate
		Laser Spot Tracker	Possible	Moderate
		FLIR	Valuable for hot spot target cuing	High
		TV	Possible for high reflectivity target cuing	Low
		Stored maps	Possible	Low
		Stored imagery of target area	Possible	Moderate
		A priori target/threat info.	Valuable	High
		Data-linked update of a priori info.	Valuable, if available	High
		Warning Receivers	Necessary	High
		Automatic target cuing devices	Valuable, if available	Moderate
Run-In to Target	Radar		Needed for terrain following/avoidance, but not covert	High
		FLIR	Helpful for terrain following, and passive	Moderate
		Stored maps	Possible	Moderate
		A priori threat info.	Necessary	High
		Data-linked update of a priori info.	To be avoided for reasons of stealth	None
		Warning Receivers	Necessary	High
Target Acquisition/ Weapon Delivery After Pop-Up	FLIR		Needed for target acquisition/Weapon delivery	High
		Radar Glints	Helpful for detection of hot or cold targets	Moderate
		GMTI, GMTT	Valuable for moving target cuing	High
		A-G Ranging	Valuable for weapon delivery computations	High
		Laser Ranger	Valuable for weapon delivery computations	High
		Laser Spot Tracker	Valuable for AFAC-designated targets	Mission-Dependent
		TV	Valuable for target detail as assist to FLIR, if available	Moderate
		Stored maps/imagery	Unlikely	Low
		A priori/linked target/threat info.	Valuable	High
		Warning Receivers	Necessary	High
		Automatic target cuing devices	Valuable, if available	Moderate

of the next; for example, the difference in scene characteristics when switching from radar imagery (preliminary target acquisition) to FLIR imagery (target acquisition at pop-up).

The simultaneous display of the information listed in Table 11 represents one potentially valuable method of gathering together or integrating the essential elements of information on a single monitor (or common grid, so to speak) and smoothing the transition from one primary sensor to the next. *If combined and sequenced appropriately throughout the mission*, these simultaneous presentations offer significant promise of decreasing the operator task loading throughout the mission while increasing survivability and the probability of successful target acquisition and weapon delivery.

Each of the recommended combinations are described in more detail in this section, accompanied by synthesized imagery where available.

TABLE 11. RECOMMENDED MULTISENSOR/DATA COMBINATIONS

Mission Phase	Primary Sensor	Secondary Sensor/ Collateral Data	Supplementary Sensors/ Data Symbology
Cruise/Navigation	Radar Imagery • RBGM • DBS • SAR	Map	• Beacon, A-G Ranging • Prebriefed CP's • Warning Receivers • Stored/Linked Threat Data
Preliminary Target Acquisition • Long Range	Radar Imagery • DBS • SAR	Stored Imagery of Target Area	Symbology • Stored/Linked Target Data • GMTI • Warning Receivers • Stored/Linked Threat Data
• Intermediate Range	Radar Imagery • DBS • SAR	FLIR • Hot Spots	Symbology • Feature Extraction/ Pattern Recognition Devices • Laser Spot Tracker/ Ranger • GMTI, A-G Ranging • Warning Receivers • Stored/Linked Target/Threat Data
Target Acquisition at Pop-Up • Stand-Off Range • Stand-Off to Minimum Range	FLIR Imagery FLIR Imagery • Processed	Radar • Glints TV Imagery • Processed	Symbology • Automatic Target Cuing Devices • Laser Spot Tracker/ Designator/Ranger • Warning Receivers • Stored/Linked Target/Threat Data • GMTI, GMTT

4.2 ACQUISITION OF DATA BASE

In order to qualitatively evaluate candidate multisensor combinations, static samples of sensor imagery were used to simulate the multisensor displays. To acquire the imagery needed for synthesis, a comprehensive inquiry of military sources was made to locate existing coincident coverage multisensor imagery of tactical and strategic targets. Due to the paucity of applicable static and dynamic imagery, a flight test was conducted in which a FLIR and a TV camera were mounted on a Hughes aircraft and flown over a flight path corresponding to previously obtained radar imagery. From the resulting data base of static and dynamic sensor imagery, a representative sample of radar, aerial photography, FLIR and TV imagery was selected for static simulation of the various combinations either by projection through transparencies or by display on a CRT. The collection of dynamic and static imagery for the data base is described in the following paragraphs.

4.2.1 Dynamic Imagery

To obtain dynamic, real-time, simultaneous coincident-coverage imagery from several sensors for superposition and visual evaluation, a flight test was conducted using the Hughes Convair aircraft. Sensors onboard included the Hughes HIPOD FLIR (315-line serial scan) and a conventional daytime TV with similar but not equal fields of view. While the FLIR was slewable over the lower hemisphere, the installation of the TV was limited to look angles between nadir and 45 degrees, along the flight path. Therefore, both sensors were set at 45 degrees to most closely approximate the forward-looking angles associated with target acquisition and weapon delivery. Accurate boresighting was not attempted. A flight plan was selected to be coincident with existing high resolution radar imagery obtained with the Hughes Forward-Looking Advanced Multimode Radar (FLAMR). Target areas included several local harbors, airports and refineries. Thus, imagery of the same scene was obtained for three sensors — FLIR, TV and synthetic aperture radar, although the SAR data did not coincide in time. The FLIR imagery was recorded on both 16 mm film and video tape while the TV was also recorded on video tape. Audio descriptions of flight parameters and scene characteristics recorded on both FLIR and TV tapes assisted in subsequent synchronization of the two images when

displayed side-by-side. The data were viewed simultaneously and the differences in image characteristics noted for assistance in determining what information from one sensor might be valuable to superimpose on the second sensor display. Video superposition was not attempted.

The second collection of simultaneous sensor video involved ground-based measurements of ground and maritime targets. It utilized a low resolution FLIR and TV which had matched fields of view and were boresighted. Manual correction of the boresight alignment was provided. The two simultaneous sensor video were automatically summed and displayed on a display monitor. The video gains were manually controlled such that FLIR only could be displayed, TV only, or any intermediate weighted sum (such as 0.75 FLIR plus 0.25 TV, 0.5 FLIR plus 0.5 TV, or 0.25 FLIR plus 0.75 TV, etc.). As the superimposed video was viewed on the monitor and adjustments in relative gain and boresight alignment were made, the data were video-taped. Still photographs of various targets and video gains were taken for subsequent side-by-side comparison and qualitative evaluation in this program.

4.2.2 Static Imagery

Static imagery of tactical targets obtained by various sensors onboard various aircraft were collected in the form of photographs, negatives, and transparencies. Although most of the imagery was not acquired by sensors operating simultaneously onboard a single aircraft, it was possible to obtain imagery of fixed tactical targets taken by a number of different sensors at approximately the same time of day and under similar weather conditions. These sensors included synthetic aperture radar, down-looking infrared linescanner, aerial reconnaissance camera, and corresponding cartography. The data can be grouped into the following sets.

Down-Looking Infrared and Reconnaissance Camera Hardcopy

The same regions are represented, but the imagery is not coincident in time or scale factor. Some measure of superposition was possible (to simulate IR plus TV) by matching the magnification ratios using photographic enlargement techniques, generating matched transparencies, and then projecting light through the two superimposed transparencies. However,

portions of the images were sufficiently misregistered that the results were inconclusive. Accurate registration would have required that the two images be digitized and spatially warped using a computer and sophisticated warping algorithms. The scope of this contract, however, precluded the development of such algorithms.

Radar and Cartography

Hardcopy of synthetic aperture radar imagery and corresponding cartography were scaled to the same magnification factor using photographic techniques. Light was then projected through the two scaled, superimposed transparencies and the resulting image photographed. This technique was used to simulate a radar display with overlaid map data (including lines of communication such as roads, rivers and railroad tracks).

Radar and Reconnaissance Photographs

Radar imagery and aerial photography were used for two purposes:

1. *To simulate the superimposed* display of real-time radar video and stored reconnaissance photos for purposes of target acquisition or verification, and,
2. To simulate the display of real-time radar video and superimposed highlight information from other real-time sensors such as FLIR or TV.

In the first case, radar image transparencies (in black/white or green) and transparencies of reconnaissance photos (black/white) of the same scene were scaled to the same size photographically. The resulting transparencies were superimposed and visually registered by aligning key features common to both images. The resulting image was then photographed in black and white and in color.

In the second case, information was extracted from the aerial photo to simulate highlight information which might be obtained from a FLIR or TV sensor. In general, FLIR or TV imagery which is presented in azimuth/elevation must undergo a spatial warping to be made compatible with a radar image which is presented in azimuth/range. Because the development of these warping algorithms was beyond the scope of this study, the available radar imagery and coincident coverage FLIR and TV imagery could not be

adequately superimposed. Instead, down-looking reconnaissance photos were scaled to match their counterpart synthetic aperture radar images, which also appear to be vertical or down-looking due to radar processing techniques. The radar and photo transparencies were then digitized and appropriately formatted on tape for entry into an interactive computer/ display system. Various image processing techniques were used to extract enhanced or highlight information from the photo to represent FLIR hot spot or TV bright spot information. This highlight data was then displayed simultaneously with the radar video on a CRT monitor in black and white and in a number of different color combinations. The CRT was photographed in color and the results used to qualitatively compare the various enhancing techniques and the various color combinations.

A large number of simultaneous sensor simulations were synthesized from the data base that has been described here. Several samples from these simulations have been selected to illustrate and assist in evaluating the multisensor display candidates. These selections are presented in the next subsection.

4.3 DESCRIPTION OF SIMULTANEOUS PRESENTATION CANDIDATES ACCORDING TO MISSION PHASE

This section attempts to accomplish two tasks simultaneously: firstly, to describe the manner in which information from the primary sensor and secondary data sources associated with each mission phase could be combined on a single display; and, secondly, to describe the way in which the combined information might assist the operator in performing the major tasks associated with each mission phase.

The discussion is divided into three types of information combinations which correspond to three different portions of the mission. These include the combination of 1) real-time radar and stored cartography for navigation, 2) real-time radar and stored (or linked) reconnaissance imagery for long range preliminary target acquisition, and 3) several real-time sensors operating simultaneously for closer range target acquisition and weapon delivery. The recommended primary sensors and secondary data sources for the various phases were previously identified in Table 11. Where available, synthesized imagery from the data base accumulated during the course of the study has been included to simulate candidate display combinations.

4.3.1 Navigation Using a Real-Time Sensor and Stored Cartography

During the cruise phase of the interdiction mission, the primary sensor has been identified as the radar. The essential task the operator performs with the air-to-ground radar throughout cruise is navigation update. This can be accomplished with varying degrees of accuracy depending on the available navigation aids and on the performance of the available A-G radar modes — 1) real beam ground map, 2) doppler beam sharpened (DBS) sector and 3) DBS patch, or 4) synthetic aperture radar (SAR) passing scene and 5) SAR telescope track. Secondary information for the task of navigation to prebriefed target areas is a map with waypoints clearly marked.

One possible means of simplifying the navigation update task is the superposition of prebriefed map data and checkpoint symbology on the radar imagery. An incrementally "moving" map display could be electronically generated from map data stored on tape in the aircraft data base and overlaid on the real-time radar display. The map overlay could be monochrome, although color is probably more effective. In addition to waypoints, shape-coded or color-coded symbology could be superimposed on the radar/map combinations to represent beacon information, prebriefed or data-linked threat location and identification, and real-time threat data obtained from onboard warning receivers. The appropriate choice of colors could be used to improve discrimination between graphics and symbols.

Superposition of map data on radar imagery at selected points in the mission would eliminate the need to look back and forth from the radar display to the displayed or hand-held map information. Also, the use of overlaid cartography might allow a lower resolution, less expensive radar to be utilized than would ordinarily be required.

4.3.2 Preliminary Target Acquisition Using a Real-Time Sensor and Stored Imagery

Preliminary target acquisition of prebriefed fixed targets typically occurs in the latter stage of cruise and preferably at long range. The primary sensor for long range target acquisition is typically the radar, using either the doppler beam sharpened sector or patch, or a synthetic aperture radar mode which, if available, could extend the detection range of large, fixed, prebriefed targets to 150 nm. Supplementary information for prebriefed targets typically consists of reconnaissance imagery of the target

area which is stored in the aircraft data base and automatically called up for display at the appropriate time in the mission. This stored imagery obtained on some previous flight could be radar, down-looking or forward-looking IR, laser line-scan, aerial photo, etc., and may have a dissimilar viewing aspect compared to the real-time sensor.

Presently, the pilot usually holds the target photo on his lap and visually correlates the photo with distinctive features on his radar display. A more desirable system would have the imagery stored on tape and presented on a second display, preferably side by side if panel space permitted, for ease of comparison. A third technique is the superposition of radar and stored target imagery on a single display, which could serve several purposes ranging from increased information content on a single display, to target verification, to more accurate offset aimpoint designation for weapon delivery computations. In both the side-by-side and superimposed cases, the mission computer keeps track of the real-time radar image coordinates and prebriefed target coordinates (by which the stored target imagery is filed), so that the stored imagery can be called up at the appropriate time for display.

As an example of preliminary target acquisition using real-time radar ground map and stored target area imagery, Figure 10a represents a low-resolution (80 ft.) synthetic aperture radar image of an air base at a range of about 25 nmi, shown here in black and white. Figure 10b is a down-looking reconnaissance photo of the target area, also shown in black and white. To simulate the combined display of these two images, the two transparencies were overlaid, aligned, and the resulting image was photographed, as shown in Figure 10d. To evaluate the effect of color, the radar image was also presented in green, as shown in Figure 10c, and the combination of the green radar image and the black and white photo is shown in Figure 10e.

Figures 10a and d or c and e can be used to estimate the possible utility of the combined presentation of radar and photo as compared to radar only. In general, the combined presentation provides additional information such as lines of communication (roads, railroad tracks, etc.) which were not imaged on the radar display. Also, the superposition of the photo can assist in offset aimpoint designation. For example, if the specific target had been marked on the stored photo (say, within the box outlined in black),

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a. LOW RESOLUTION SAR (BLACK/WHITE)

b. DOWN-LOOKING PHOTO (BLACK/WHITE)

c. LOW RESOLUTION SAR (GREEN)

d. SUMMATION OF SAR PLUS PHOTO (BLACK/WHITE)

e. SUMMATION OF SAR (GREEN) PLUS PHOTO (BLACK/WHITE)

FIGURE 10. SIMULATED SIMULTANEOUS PRESENTATION OF LOW RESOLUTION SAR IMAGE AND RECONNAISSANCE PHOTO

the designation of that point by a movable cursor, after superposition of the photo on the radar, would enable the target coordinates (referenced to the radar) to be entered into the mission computer. During descent and low-altitude penetration, the computer would continue to update coordinates relative to the aircraft, such that at pop-up, an EO imaging sensor could be automatically slewed to the appropriate line of sight.

In practice, radar/photo summation, as exemplified by Figure 10d, may present too much data to the pilot. It may be preferable to extract only salient information from the stored image for display on the radar. For example, the photo could be thresholded such that only the brightest shades of gray would be superimposed on the radar, possibly in a different color. Or the photo could be edge-enhanced such that only "outlines" would be overlaid on the radar, thus providing major lines of communication as well as outlining of high contrast areas. In this manner, the operator can be provided the required information without significantly increasing the task of interpretation.

In general, the use of false color coding in combined displays may assist in differentiating information or imagery from several sources. The use of green for the radar image in the combination of Figure 10e does not appear to offer significant advantages. However, if it had been possible to also color code the photo, for example, in red, more distinct definition of radar glints from bright objects in the photo would have been possible.

The display of important additional data can be achieved by overlaying symbology on the combined imagery of either Figure 10d or e. On the black/white display, the symbology can be intensity-coded, shape-coded, and even flashed to increase discrimination. A color display, however, has the advantage of color-coded symbol capability. In either case, critical information such as emitter locations and identifications obtained from warning receivers, threat data stored in the data base or linked to the aircraft, moving target indications, and a variety of other data can be provided in an attention-focusing manner within the context of the primary sensor imagery.

As in the previous case of combined radar and cartography, the use of imagery (raw or processed) superimposed on the radar display may enable a lower resolution, less expensive radar to be utilized than would ordinarily be required.

4.3.3 Target Acquisition Using Real-Time Sensors

Three representative target acquisition cases are considered:

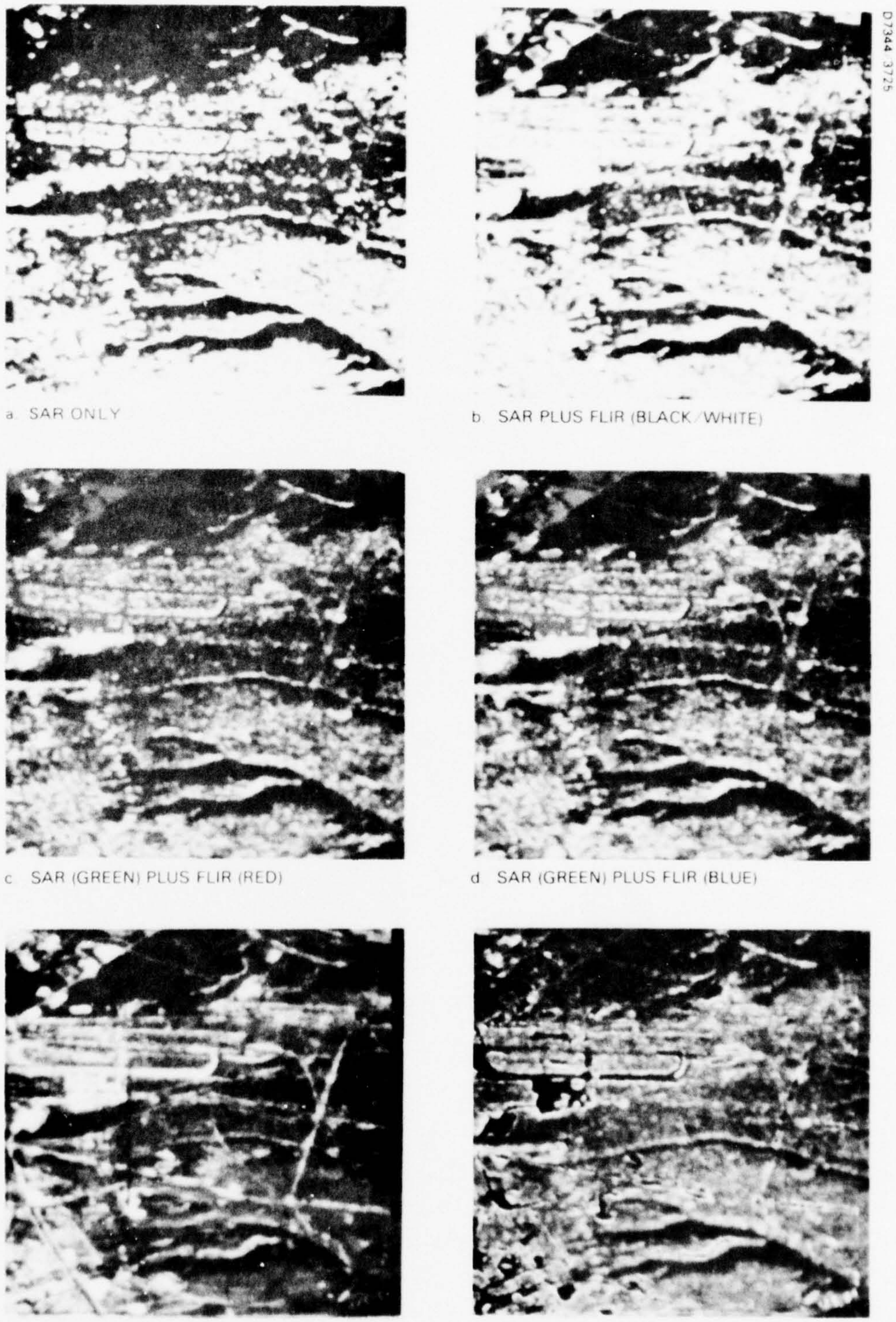
1. Preliminary target acquisition at long range, descent, run-in, and pop-up at stand-off ranges greater than 50,000 feet.
2. Preliminary target acquisition at intermediate range, descent, run-in, and pop-up at stand-off ranges less than 50,000 feet.
3. Minimum range pop-up.

Case 1

The primary sensor for preliminary target acquisition at long range is ground mapping radar, the desirable modes being doppler beam sharpened sector or patch, and synthetic aperture radar (SAR) passing scene or telescope track. Assume preliminary target acquisition in this case was accomplished using low resolution SAR with the possible superposition of prebriefed map or reconnaissance imagery retrieved from the aircraft data base. The aircraft then descends for low-altitude penetration. If long stand-off range pop-up (in excess of 50,000 feet) is desired by the pilot, then the radar ground map typically remains the primary sensor at pop-up. However, it is possible that the high performance FLIR may also be capable of providing useful information at these ranges. This FLIR-derived information could be superimposed on the radar display to augment the radar information or cue the pilot by indicating "hot spot" locations, or large target complexes.

To simulate this displayed combination of primary radar imagery and FLIR highlight data at stand-off range pop-up, the SAR image and optical image previously shown in Figure 10 were digitized and stored on magnetic tape. The radar and simulated FLIR data were then displayed on a CRT in black/white and various colors and photographed. Samples of the results are shown in Figure 11 for purposes of comparison.

Figure 11a represents the radar ground map at pop-up, displayed in black and white. Low resolution, poor quality imagery was deliberately chosen here to simulate the type of radar imagery upon which the pilot must often depend. To simulate the combination of radar and FLIR highlight imagery at pop-up, the radar image of Figure 11a has been summed pixel by pixel with the optical imagery, each with a gain of 0.5. This simple mixing of the two images in black/white is shown in Figure 11b. To estimate



a. SAR ONLY

b. SAR PLUS FLIR (BLACK/WHITE)

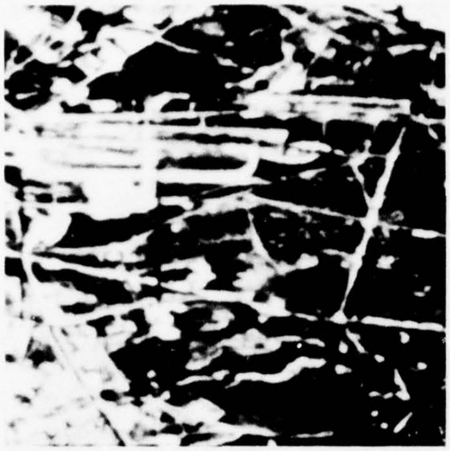
c. SAR (GREEN) PLUS FLIR (RED)

d. SAR (GREEN) PLUS FLIR (BLUE)

e. SAR (RED) PLUS FLIR (GREEN)

f. SAR (BLUE) PLUS FLIR (RED)

FIGURE 11. SIMULTANEOUS PRESENTATION OF LOW RESOLUTION SAR IMAGERY AND SIMULATED FLIR IMAGERY



g. FLIR (black and white)

the possible value of false color coding of the two sensor outputs. Figure 11c shows the radar in green and the simulated FLIR in red. In Figure 11d, the radar remains green while the FLIR information is in blue. In Figure 11e, the radar ground map is displayed in red and the FLIR in green. In Figure 11f, the radar is in blue, the FLIR in red. At closer ranges, during target recognition and weapon delivery, the electro-optical sensor (FLIR or TV) simulated by Figure 11g replaces the radar as the primary sensor.

From the simulated multisensor displays of Figure 11, color coding of the two sources of information appears preferable to the black/white combination for this particular example. Comparison of Figures 11c and e illustrate why red should be used primarily for cuing rather than for background imagery. The red radar background distracts the attention from the points of interest such as the green air strip and lines of communications. The opposite combination, red on green, appears far superior. Figure 11f illustrates the 3-dimensional effect which is obtained when blue is used for the background imagery and supplementary information is presented in red. (In this case, the optical image was differentiated to produce the edge-enhanced or outlining effect shown.)

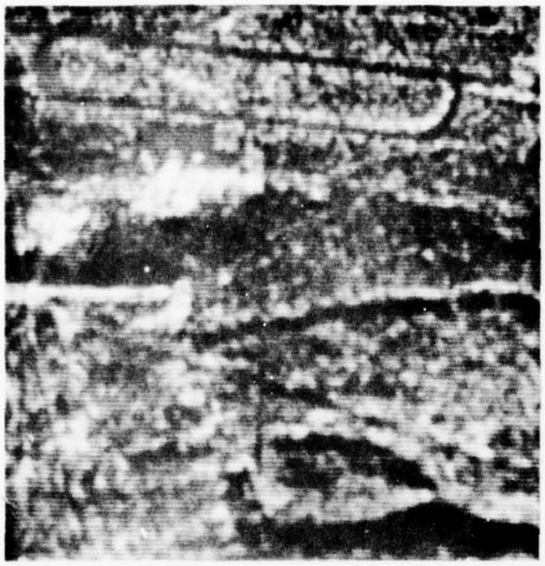
The simple mixing of the two sensor outputs shown in Figures 11b through Figure 11e may result in an excess of data and may also mask points showing strong radar glints or FLIR hot spots. An alternate technique is to process the FLIR output so as to extract salient information, then superimpose only that processed or enhanced FLIR information on the

radar display. As an example, Figure 12a shows the simple mixing of radar in green and simulated FLIR in blue, each at a gain of 0.5. By comparison, in Figure 12b, an edge enhancement technique has been used. The radar is again displayed in green while a simple linear differentiation has been applied to the simulated FLIR image and the resulting "outlines" are displayed in blue. This process results in an improved definition of major lines of communication as well as outlining of high contrast objects.

In Figures 12c and d, the appropriate radar pixels are "replaced" with the FLIR highlight data to prevent masking of FLIR information. In Figure 12c, the optical or FLIR image has been thresholded at 90 percent such that only features or objects with the greatest temperature differentials would be placed on the radar display. Since each blue pixel, representing a thresholded FLIR element, replaces a green radar pixel, some strong radar returns may be lost. To avoid this loss of potentially useful radar information, a third color could be used to denote those points at which both the radar signal and the FLIR signal were above a certain level. In Figure 12d, the FLIR has been thresholded at 70 percent of maximum intensity, the "brightest" shades of gray are displayed in blue in place of the radar, and those points at which both the radar and the FLIR exceed 70 percent of their respective maxima are color coded in orange.

Ultimately, it should be possible with sophisticated image processing techniques to perform pattern recognition and feature extraction operations on one sensor image and display that information by means of graphics and symbology either on the same sensor image or on a second sensor image. LOCs such as roads and railroad tracks could be extracted and displayed as maximum intensity or color-coded lines on the radar display. Vehicles such as tanks and trucks could be recognized with estimated confidence levels by appropriate processing of FLIR or radar returns. This target cuing information could then be displayed as a coded symbol at the proper location on the FLIR or radar display.

On each of the synthesized sensor combinations shown in Figures 11 and 12, color-coded and shape-coded symbology could be used for other sensor data such as GMTI and warning receivers, as well as stored and linked threat data.



a. SUMMATION OF SAR PLUS FLIR

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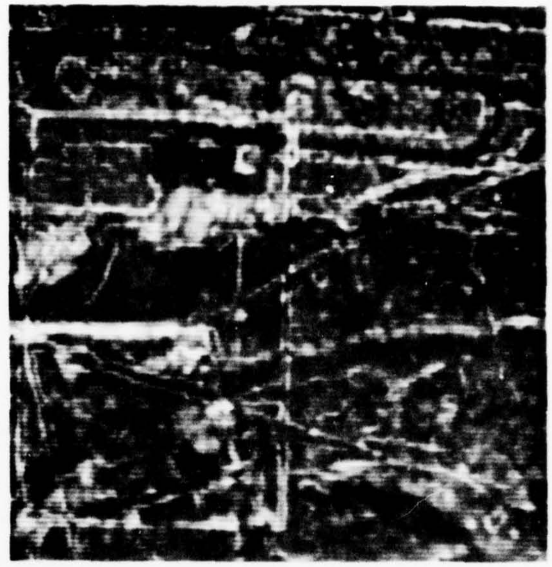
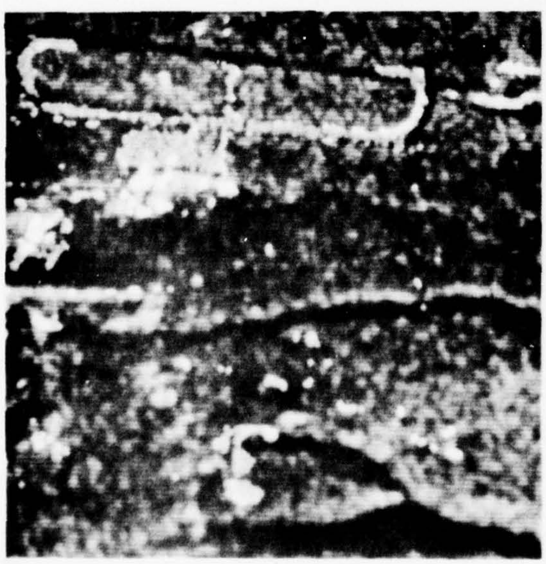


b. SAR PLUS EDGE-ENHANCED FLIR



c. SAR PLUS THRESHOLDED (90%) FLIR

d. SAR PLUS THRESHOLDED (70%) FLIR PLUS COINCIDENT RADAR GLINTS AND FLIR HOT SPOTS

FIGURE 12. SIMULTANEOUS PRESENTATION OF SAR IMAGERY AND PROCESSED, SIMULATED FLIR IMAGERY

Case 2

This case pertains to intermediate stand-off range pop-up which is applicable to three types of targets: 1) prebriefed targets, 2) targets handed off via laser designation, as in hunter-killer teams or situations involving an AFAC, and 3) targets of opportunity located in prebriefed target-rich areas. Two examples related to targets of opportunity will be considered here: firstly, the combined use of radar as the primary sensor and FLIR as the augmenting sensor to acquire targets of opportunity; and secondly, the use of FLIR as the primary sensor and radar as the augmenting sensor.

These examples attempt to illustrate how FLIR hot spot information can be used to cue the operator to potential targets on the radar display, how retained radar imagery can provide a context for narrow field-of-view FLIR imagery, and how radar glint information can be used to cue the operator to targets on the FLIR display. The examples are described separately. However, in practice, they can be sequenced for use in one target acquisition/weapon delivery operation.

Radar and FLIR

The primary sensor for preliminary target acquisition is assumed to be the radar. The example shown in Figure 13a is high resolution (10 ft.) SAR at a range of about 15 nmi. displayed in black and white. A river crossing is evident (an existing bridge and a pontoon bridge in construction). The pilot may choose to designate the region showing several strong radar returns and thereby slew his FLIR to that direction. One of the simplest techniques for extracting salient FLIR information and presenting it on the radar display is to threshold the FLIR output and use the symbol generator to place a single small dot at the centroid of each hot spot detection. Figure 13b shows each such hot spot as a red dot for cuing purposes. On a monochrome display without multicolor capability, a bright white flashing dot could be used or a shape-coded symbol.

Other sensor information can also be displayed by means of symbology. The yellow diamond represents an emitter whose coordinates have been data-linked to the aircraft. A green triangle could be used to represent a radar ground moving target indication.

Assuming the pilot then designates the target of interest with his movable cursor, the coordinates are automatically entered into the mission computer, and he descends rapidly for low altitude ingress. During run-in, the target position relative to the aircraft is continually updated by the computer, aided by the navigation systems. If pop-up occurs at less than 50,000 feet slant range, the pilot typically chooses to go directly to his imaging sensor (for target reacquisition) which is usually a FLIR. (All examples shown represent cases in which the pilot must use his multipurpose display rather than direct visual/HUD due to visibility, nighttime, etc.) Since detection and recognition are normally accomplished with the narrow field-of-view mode (approximately 1 degree to 3 degrees), it is critical that the FLIR be automatically slewed and accurately pointed in the right direction. Should the target not be within the field of view, the pilot must slew the FLIR manually or return to the radar for redesignation of the target.

The display shown in Figure 13c is one technique for going directly to an EO display at pop-up while maintaining a radar border for context in case the entire radar display must be recalled for target redesignation. In this case, the scale factors of the EO image and the radar are obviously very different. Only one point is correlated between the EO and radar, that is, the single point designated by the pilot before descent. The error in this correlation is primarily a function of the errors introduced in target position update during run-in. If the target designated were toward the edge of the display, the EO image would also be located at that position. If, in this example, the pilot could not reacquire and was required to return to the radar image, the presence of the river within both sides of the radar border might facilitate the necessary visual reorientation.

This insert technique for maintaining radar context can also be used with other radar formats. Figure 14a shows a doppler beam sharpened radar ground map in a PPI format. Preliminary verification of target complexes could be achieved by briefly overlaying stored cartography, as shown in Figure 14b, on the radar ground map. After designation with a movable cursor of the region showing indications of storage tanks, the FLIR is automatically slewed to that direction. The FLIR image appears on the radar display centered at the point of designation, as shown in Figure 14c. This simulated combination represents 400 FLIR lines inserted in an 875-line

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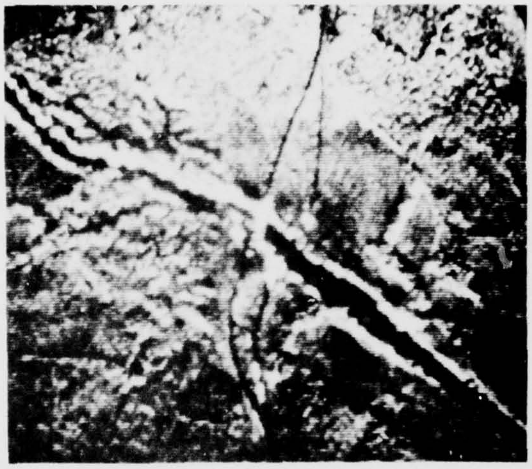
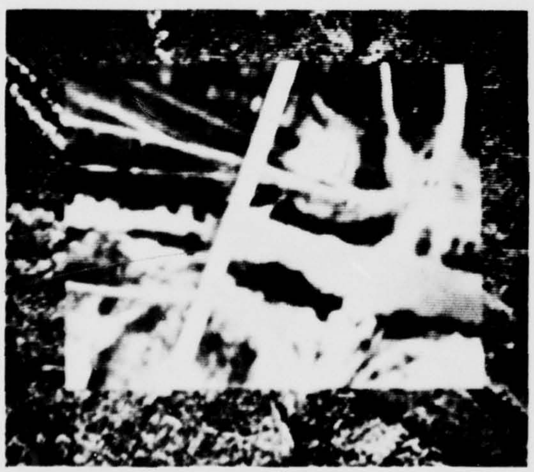


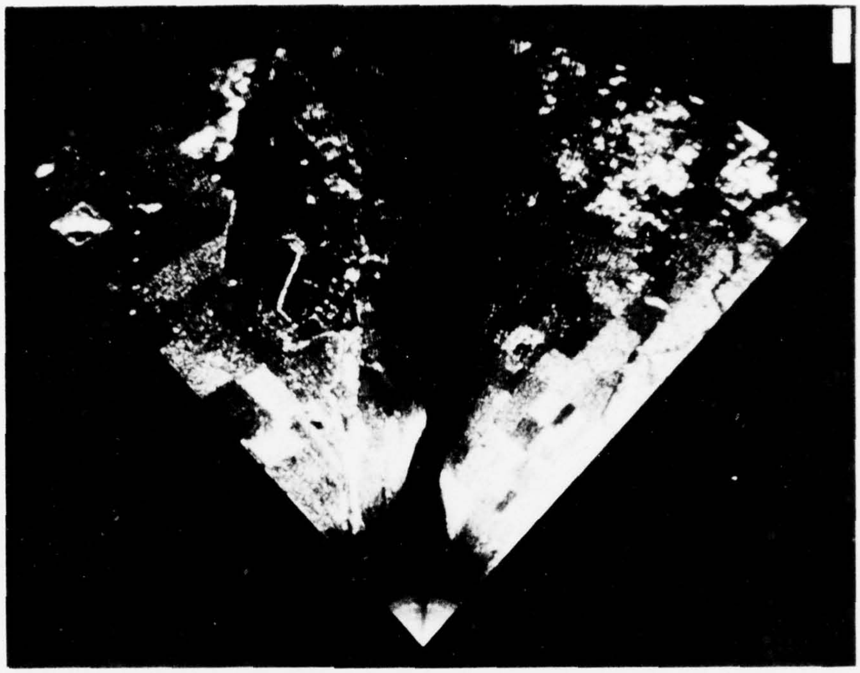
a. PRIMARY SENSOR: SAR (10 FT. RESOLUTION)

b. PRIMARY SENSOR: SAR
SECONDARY SENSOR: FLIR "HOT SPOTS",
SUPPLEMENTARY DATA: EMITTER LOCATION

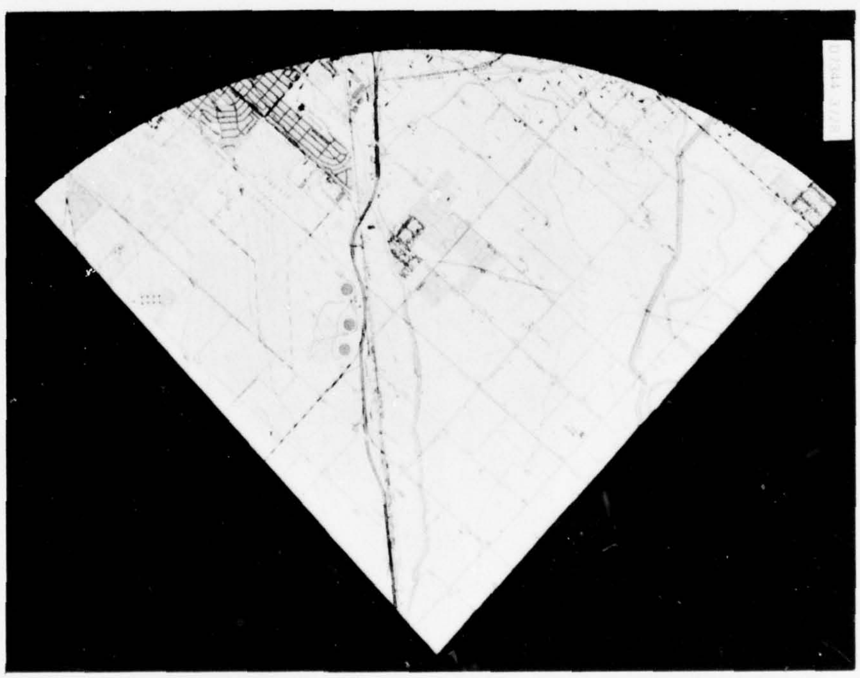


c. PRIMARY SENSOR: EO
SECONDARY SENSOR: SAR "BORDER" TO MAINTAIN CONTEXT AND ORIENTATION FOR POSSIBLE RETURN TO RADAR IMAGE

FIGURE 13. SIMULATED SIMULTANEOUS PRESENTATIONS USING SAR AND EO SENSOR FOR PRELIMINARY TARGET ACQUISITION AND REACQUISITION AFTER POP-UP

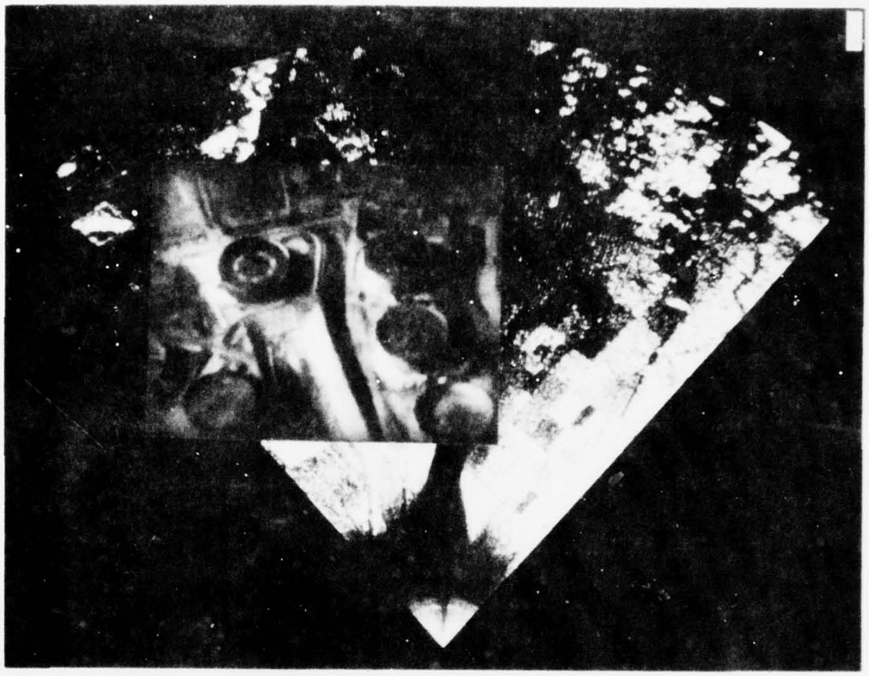


a. DBS radar ground map.

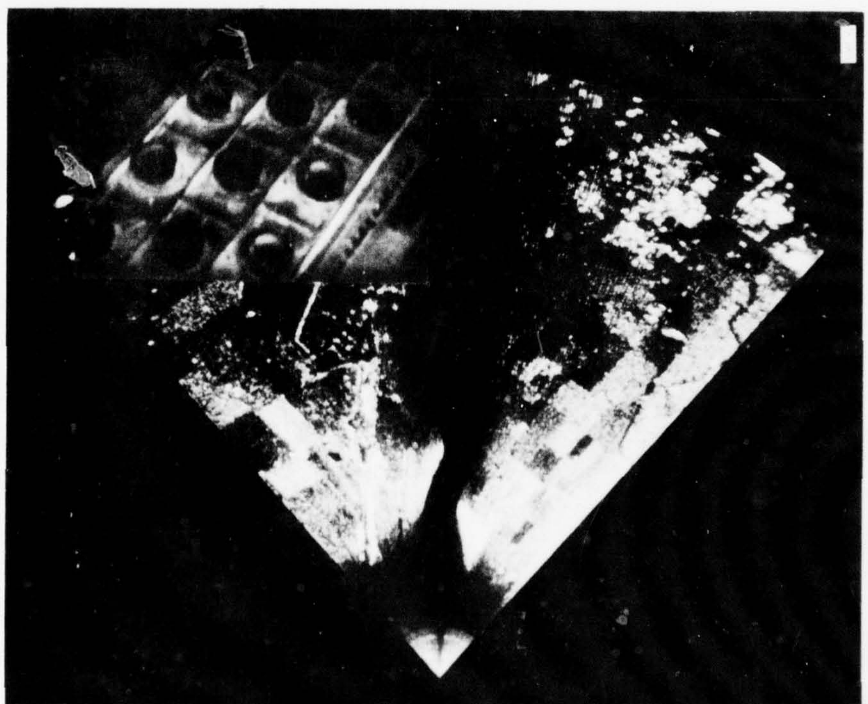


b. Stored cartography corresponding to DBS ground map.

Figure 14. Target acquisition using radar and FLIR imagery, Case 2. (Sheet 1 of 2)



c. FLIR insert on DBS map, first target complex.



d. FLIR insert on DBS map, second target complex.

Figure 14. Target acquisition using radar and FLIR imagery, Case 2. (Sheet 2 of 2)

radar display. Should this not be the desired target, the FLIR can be manually slewed and the FLIR insert moved correspondingly, or the pilot may return to radar-only for redesignation of a second potential target. Assuming he now designates the storage tanks at the upper left of the radar display (which are visible in the radar image of Figure 14c even with the FLIR insert present and verified with Figure 14b), the resulting display would appear as in Figure 14d. Because the designated point is near the display edge, fewer FLIR lines (about 300) are displayed. However, the display of the FLIR FOV could be centered on the radar display if desired, irrespective of the position of the designated point.

With the insert type of simultaneous presentation, flashing, shape-coded or color-coded symbology representing threats, GMTI, etc., could be overlaid on either the radar or the FLIR imagery. However, placing them on the radar imagery would provide cuing information for subsequent cursor designation and pointing of the FLIR sensor.

<u>FLIR and Radar</u>

At ranges of less than 10 nmi, an electro-optical imaging sensor such as FLIR or TV is usually the primary sensor. Just as the FLIR may be helpful in cuing the pilot to a point on the radar display for longer range target acquisition, so the radar could possibly provide cuing information on the FLIR display for shorter range target acquisition. Using the imagery in Figure 15a to simulate a FLIR or TV sensor display, we see a wide and a narrow canal, a wide double road or highway, two narrow roads and a highway intersection. Figure 15b is a low resolution (80 ft.) SAR image of the same scene. By photographic processing techniques, the radar glints were extracted from the SAR image and color-keyed in green, resulting in the composite image in Figure 15c. Information which has now been added to the FLIR or TV image includes the indication of an irrigation lock at the junction of the two canals and the possible presence of one or more vehicles at the highway crossing. Were this a true FLIR image, the presence of white/hot (or black/hot) objects at the crossing would further substantiate the presence of moving vehicles. The extended radar returns at the left are reflections from the road bank.

Referring back to the scene insert in Figure 13c, the use of TV as the primary sensor can provide visual detail of vehicles and the use of FLIR as the primary sensor can provide thermal indications of moving or still-warm

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a. LOW RESOLUTION SAR

b SIMULATED TV OR FLIR

c. TV OR FLIR PLUS RADAR GLINTS

FIGURE 15. SIMULATED SIMULTANEOUS PRESENTATION OF ELECTRO-OPTICAL SENSOR IMAGE AND AMPLITUDE-THRESHOLDED RADAR

vehicles. However, neither sensor is likely to detect a cold vehicle in foliage. The use of amplitude-thresholded radar returns or glints superimposed on the FLIR, for example, could cue the pilot to a cold vehicle or man-made target, or verify the presence of a hot or moving vehicle. A radar moving target indication displayed as a symbol would provide further verification of a moving vehicle. It would also be desirable to associate particular colors with particular sensors, if color coding is utilized, such as green for radar glints and red for FLIR hot spots.

Symbols can be overlaid on the FLIR or TV azimuth-elevation display for anticipated target position, laser spot tracker coordinates, laser designator/ranger coordinates (numerical range could be presented adjacent to the symbol), threat location from warning receivers, a priori or data-linked threat locations, and moving target indication or fixed target track position.

Case 3

This case pertains to minimum range pop-up after run-in to target. By maintaining a low-altitude penetration profile until very close to the target (previously cued or acquired), the aircraft can take maximum advantage of terrain masking from ground defensive systems, thereby reducing its susceptibility to enemy detection and attack. However, pop-up at minimum range also means the pilot has less time for target re-acquisition and weapon delivery, with timelines possibly as short as 10 seconds.

It is assumed that the primary sensor at these ranges is an EO imaging sensor, such as FLIR or TV, which has been suitably cued to allow the use of its narrow field of view mode. This attack mode often depends on storing the target coordinates in the inertial navigation system prior to the penetration portion of the attack profile. The EO FOV must then be consistent with the resulting navigation and pointing errors. If both a FLIR and a TV sensor were available, the possible augmentation of one sensor by the second should be considered to aid the operator in the target acquisition problem. Since each sensor provides different information about a target (the FLIR image is based on apparent temperature differences within a scene, while the TV image is based on differences in light reflectivity), the combination of the two sensor images in some optimum fashion may result in enhanced target acquisition performance.

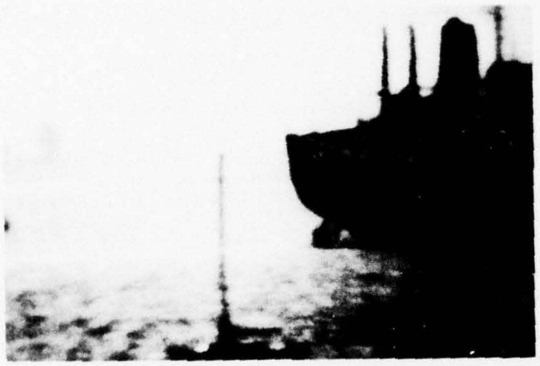
An example of combined FLIR and TV imagery from the imagery data base acquired during the study is shown in Figure 16. Figure 16 corresponds to a scene as sampled and displayed by a TV system. Figure 16 corresponds to the same scene as sampled and displayed by a FLIR system. As indicated in Section 4.2, the TV and FLIR have similar magnifications and their boresight can be manually adjusted. Both sensors are operating simultaneously and their video can be mixed with variable gain control of each. At 0.5 gain, for example, hot-bright targets will be double the intensity of cold-bright or hot-dark areas.

Figure 16 shows the two videos mixed and only slightly misregistered. Several observations can be made by comparing the mixed video to the TV or FLIR video only. Firstly, there is more detail available in the mixed video. Note that the ship is only a silhouette in the TV mode due to lighting geometry. Note also that the FLIR only mode presents the ship as saturated due to the relatively large thermal gradient from background to ship. Mixing of the same TV and FLIR videos, without any processing or enhancement, allows more features of the ship to be resolvable, as evidenced by the figure.

Secondly, the mixed video represents a more complete and accurate set of information. As an example, note in Figure 16b that the boat's mast is shortened because of a signal processing anomaly in the FLIR. The TV of Figure 16a shows the mast at its correct height; thus, the mixed video preserves this information.

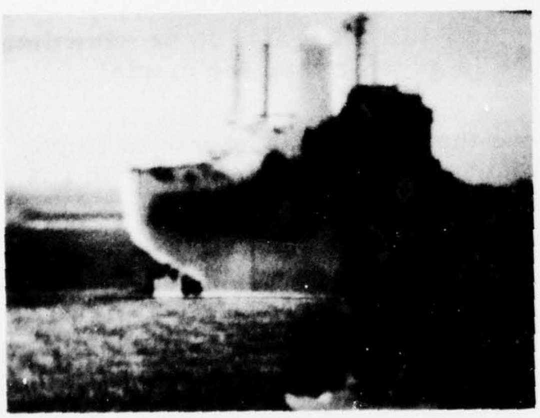
Thirdly, the subsets or local areas of the TV and FLIR images generally have different video amplitudes and modulation characteristics. Thus, in some cases, the mixed video may result in an effective "filling in" of low modulation areas of one sensor with image detail from the second sensor.

Fourthly, it can be seen that the effects of image misregistration do not necessarily result in degraded image quality. In Figure 16c, the TV and FLIR are slightly misregistered. In Figure 16d, they are more grossly misregistered, yet the image is still highly recognizable and informative. Note also in Figure 16c an edge enhanced (or outlined) and sculptured (or 3-dimensional) effect due to the combined effects of the slight misregistration and the TV/FLIR video amplitude differences. This effect is much more pronounced when viewing the dynamic mixed imagery on the display, as compared to the static photographs presented here.

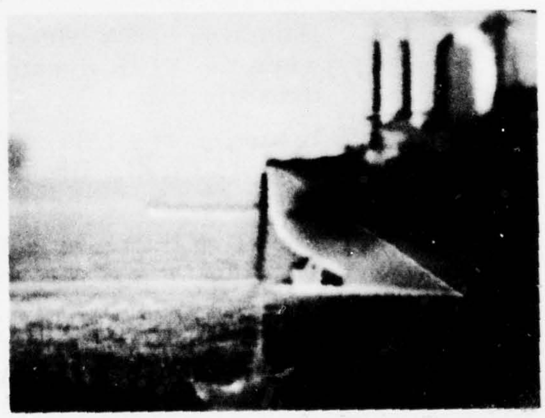


a. TV only.

b. FLIR only.



c. TV plus FLIR slightly misregistered.



d. TV plus FLIR grossly misregistered.

Figure 16. Summation of TV and FLIR video showing effect of misregistration

An important corollary to the above observation is that pixel-by-pixel registration may not be required or even desirable in simultaneous presentations. Should this be the case, the complexity of any required hardware and software associated with matching and mixing video from different sensors would be considerably reduced. Because of the impact of this consideration on realizing a fieldable simultaneous sensor system, additional effort in the form of human factors measurements is warranted to determine the allowable tolerances in mixing TV/FLIR as well as FLIR/radar.

The mixed video of Figure 16 involved a simple summation of the FLIR and TV signals. However, a number of more sophisticated processing and mixing techniques could be considered for future evaluation including:

- Interlacing of the two video fields.
- Alternation of the two images with variable frequency.
- Thresholding of one video signal and placement of only the highlights on the second video image. FLIR hot spots could be placed on the TV display or TV bright spots placed on the FLIR display.
- Edge-enhancement of one video image and placement of only the outlines on the second video image. Temperature differences from the FLIR scene could appear as bright outlines on the TV display or brightness differences from the TV scene as bright outlines on the FLIR display.
- Insertion of TV video where the FLIR saturates to provide detail when the FLIR dynamic range is greater than the display dynamic range.
- Insertion of FLIR video where the TV is dark, again to compensate for the limited dynamic range of the display or to fill in detail where there is none.
- Sampling of the modulation in the FLIR scene and insertion of TV video wherever there is no detail in the FLIR image, or vice versa.
- Color coding of any of the above combinations, preferably using red for FLIR information and green or blue-green for TV.

Several of the above techniques could also be applied to the FLIR display only (or the TV only) such as amplitude thresholding to accentuate hot (or bright) spots, edge enhancement to outline areas of constant temperature (or brightness), or assigning different colors to different level slices such that the dynamic range of the display is artificially enhanced by the use of false or pseudocolor.

4.4 CONCLUSIONS

To determine the most logical simultaneous sensor display candidates within the structure of the interdiction mission, the selection criteria used were: 1) criticality of the various sensors and data to the mission and 2) utility to the operator of combining those sensors or data on a single display. Because very little attention has been previously concentrated in this area (as demonstrated by the literature search in Appendix A) and due to the exceedingly limited amount of existing coincident coverage multisensor imagery, the values assigned to criticality and utility here are qualitative estimates. Nonetheless, definite recommendations emerge. The following simultaneous sensor presentations appear to offer significant advantages for increasing the probability of mission success and for decreasing the operator task loading:

- The simultaneous display of real-time radar ground map and stored cartography and waypoint data to assist in accurate navigation to the prebriefed target area.
- The simultaneous display of real-time radar ground map and stored reconnaissance imagery of prebriefed targets for preliminary target acquisition at long range, for target verification, and for offset aimpoint designation.
- The simultaneous display of real-time radar ground map and real-time FLIR data at stand-off ranges to provide thermal gradient indications for cuing the operator to possible targets on the radar display. This could be particularly valuable for the acquisition of large target complexes or for hot spot detections corresponding to targets of opportunity such as moving vehicles.
- The simultaneous display of real-time FLIR imagery and radar glints for cuing the operator to man-made objects on the FLIR display which could be cold or hot.
- The simultaneous display of real-time FLIR and real-time TV, processed and mixed in an optimum fashion such that certain types of targets may be acquired in shorter time or at longer range.

Based on a qualitative evaluation of the simultaneous presentations which were simulated from a very limited imagery data base, the following observations concerning the display of these data can be made:

- The simple summation of imagery from two sensors may result in lower performance than could be achieved with one sensor only. A major factor in achieving a synergistic combination

of multisensor data is the selective extraction of salient information from one sensor image for superposition on the second sensor image. Thus, the key to effective multisensor integration and display is image processing.

- Of the various image processing operations considered in this study, two techniques show particular promise: 1) thresholding of one sensor image and subsequent display of this highlight data on a second sensor image (for example, FLIR hot spots in red on radar ground map in black/white or green, FLIR hot spots in red on TV imagery in black/white or blue-green), and 2) edge enhancement of one sensor image and subsequent display of these outlines on a second sensor image (for example, FLIR outlines of roads and high thermal gradient objects displayed on radar, TV outlines of high contrast objects displayed on FLIR). Special processing operations should be considered to ensure that essential information from one sensor is not masked or replaced by highlight information from the other sensor.
- As more sophisticated image processing techniques evolve for feature extraction and pattern recognition of roads, rivers, tanks, trucks, etc., from typical sensor imagery, provision should be made to display the results of these automatic feature and target cuing devices (for example, as coded symbols or graphics superimposed on FLIR or radar imagery).
- Exact pixel by pixel registration of two superimposed sensor images may not be required or even desirable. FLIR/TV combinations have shown that slight misregistration can result in edge enhancement and "sculpturing" of the imaged target. By reducing the registration requirements, the complexity of the hardware/software required to register and mix two sensor video could also be substantially reduced.
- Although all of the simultaneous presentations could be presented on a black/white or single color display, color coding of the different sensor inputs appears to be more effective in that it enables the observer to easily differentiate between data sources.
- Associating a specific color with a specific sensor seems highly desirable, especially for highlight data. Examples are red for FLIR hot spots, green for radar glints.
- Red does not appear to be an appropriate color for background or primary sensor imagery, but is excellent for presenting highlight data from another sensor or for overlaying threat symbology on radar or FLIR imagery.

Future efforts should include: 1) the acquisition of appropriate simultaneous, coincident coverage multisensor imagery, 2) the spatial warping and registration of that imagery, 3) the application of a variety of image processing operations, and 4) the capability to display the registered, processed imagery in a variety of color combinations. Thus, quantitative measurements of operator performance could be made as a function of image misregistration, image processing or enhancement technique, and false color selection.

5.0 IMAGE PROCESSING CONSIDERATIONS FOR SIMULTANEOUS SENSOR PRESENTATIONS

A number of promising simultaneous presentations were identified in Section 4.0 for use in an interdiction mission. Implementation of these various simultaneous presentations requires that the two (or more) types of information to be combined first be made compatible (preprocessed) for image superposition, then optimally processed and mixed for subsequent display on a single monitor. This section discusses the preprocessing and processing requirements for simultaneous presentations, such as reformatting of the two input images, correcting for image misregistration, enhancing or selecting salient features in either image, and displaying the two images simultaneously. Section 6.0 will then describe the hardware required to implement these processing operations.

Three types of simultaneous presentations have been recommended as promising candidates:

1. Real-time sensor plus stored cartography,
2. Real-time sensor plus stored reconnaissance imagery,
3. Real-time sensor plus real-time sensor such as radar plus FLIR (or TV) highlights, FLIR (or TV) plus radar highlights, FLIR plus TV, etc.

The simplest case is that of combining primary sensor video and cartography, where key features such as roads, rivers, coastlines, etc., are available for matching and superposition.

A more difficult undertaking is the combination of real-time sensor video and a priori imagery stored in the aircraft data base (or imagery data-linked in flight), requiring the correlation of two images which may have different aspect angles, scale factors, and scene characteristics.

The most complex case is that of combining the video from two real-time sensors. In general, the two sensors may have differences in

- Format (example: radar is azimuth versus range while FLIR is azimuth versus elevation)
- Line-scan (example: radar may have 875 TV lines and FLIR 525 or vice versa)
- Field-of-view (example: radar may vary in azimuth from 20 to 120 degrees, FLIR FOV from 1.5 to 20 degrees, and TV FOV from 0.5 to 40 degrees)

- Update rate (example: radar may take several seconds to form one frame while FLIR is updated at 1/15 or 1/30 second per frame, and TV at 1/30 second per frame)
- Orientation (example: two images may have errors in boresight and rotation (image roll)).

This section discusses the most complex case, i.e., the processing requirements for combining video from two real-time sensors. The same considerations can be readily applied to the two simpler cases involving a real-time sensor and stored or data-linked imagery, or cartography.

The processing operations fall into four areas, as shown in the system block diagram of Figure 17:

1. Preprocessing and coordinate transformations of the input sensors such as radar, FLIR, or TV (as well as data-linked imagery or stored imagery from the aircraft data base),
2. Determining and correcting misregistration between images. (A registration or boresight computer determines the relative shifts between selected sensor imagery and provides outputs for pre-detection or post-detection correction of the sensor data.)
3. Applying image processing and enhancement operations to either image,
4. Combining the processed video from the sensor (or stored/linked imagery) for input to a display.

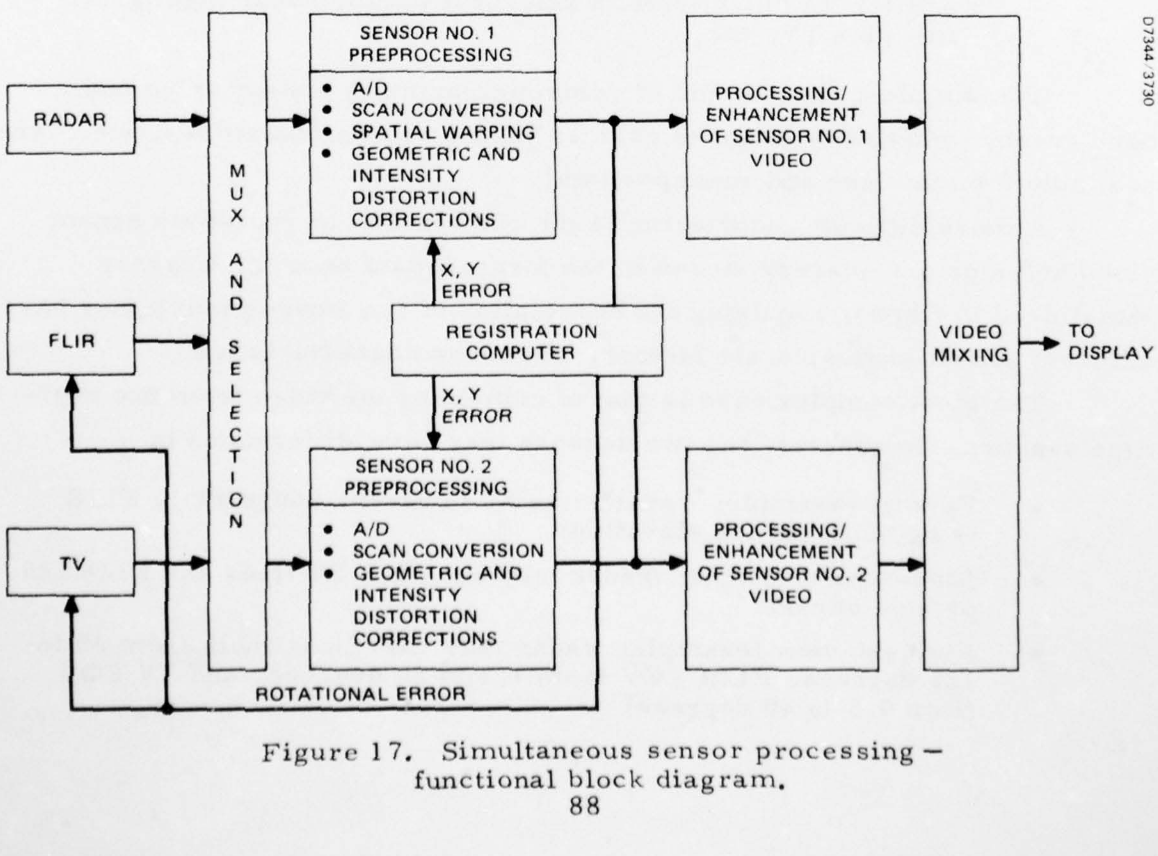


Figure 17. Simultaneous sensor processing — functional block diagram.

These four operations are described below. A number of possible correction and processing operations are described for the sake of completeness and to indicate what a highly sophisticated system could include for greatly enhanced capability. In practice, however, high performance operational systems can be implemented utilizing only a selected number of the possible functions identified here and often with far less stringent accuracies than these functions are capable of.

5.1 PREPROCESSING

The signal preprocessing step immediately follows the signal acquisition from the sensors. The sensor video data are digitized with A/D converters; thus, two A/D converters are required, as a minimum. The multiplexer shown in Figure 17 controls the inputs to the A/D converter and selects from various inputs to be displayed. The microprocessor-controlled scan converter is an important element in reformatting the image line and scan parameters to a common standard. Various error correction inputs from the registration computer also enter here for horizontal and vertical scaling and shift. All the correction functions are closely interrelated, so the preprocessing steps shown in the initial boxes may be combined in an actual system. The following sections consider the details of various possible corrections which could be performed if required.

5.1.1 Coordinate Transformation

A reformatting of one sensor input may be required to achieve coordinate compatibility with the second sensor input. For example, the display of FLIR hot spots on a radar display requires the transformation of the azimuth elevation coordinates of the FLIR data to the azimuth-range coordinates of the radar image. Thus, a first order warp could be used in which the FLIR image plane (perpendicular to the sensor line of sight) is warped into the radar footprint, based on own-aircraft altitude and FLIR depression angle. This coordinate transformation could be accomplished as the data are entered into the scan converter memory. The simplest technique would be to command the symbol generator to place a dot on the radar display at the coordinate-transformed location of each thresholded hot spot detection.

The placement of radar glint data on FLIR imagery would require a warping of the radar footprint into the FLIR imaging plane. This computation is the inverse of that required to warp the FLIR into the radar.

5.1.2 Geometrical Distortion

In the most general form, geometrical distortion can be visualized by considering a rubber sheet stretching analogy. If a rectangular grid is applied to a flexible sheet, then arbitrary stretches of the sheet will distort the grid to a series of intersecting curved lines.(Ref. 2) These distortions can be caused by imperfections in the imaging system, nonlinear deflection in the image sensor, or elevation differences in the observed scene. The fixed sensor distortions (such as pincushion or barrel distortion) are relatively small and vary slowly with time. They can be removed before image detection by compensation of the deflection which is generally done by analog techniques for simplicity.

In the case of elevation or terrain height differences, certain local dynamic scene-dependent distortions may occur in an image from hills, mountains, buildings, etc., in the field-of-view. Dynamic correction of these distortions is very difficult because the scene changes rapidly and a fast, sophisticated processor needs to continuously correlate frames of information and provide local distortion update corrections. It is not apparent that this correction, although desirable, is necessary for this application. Although no details are described here, this type of correction is feasible and extremely useful for terrain avoidance close-range systems. It is possible that the use of an area correlation technique for registering two sensor images may automatically provide a degree of correction for local dynamic distortions, thus relieving some of the difficulties and complications of this case. This consideration is beyond the scope of this contract, and no further discussion will be given here.

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[2] A. A. Sawchuk, "Correction of Imaging System Geometrical Nonlinearities in Real Time," submitted to IEEE Transactions on Computers.

5.1.3 Intensity Nonlinearity

The signal output of an image sensor may not be a strictly linear function of the brightness at a point in the scene.(Ref. 3) In addition, there are variable position-dependent shading effects; most sensors are brightest in the center and drop off toward the edges. Some of these effects can be compensated by optical design and by analog electronic techniques. Any residual effects could be compensated digitally, if necessary, by the use of a fixed or variable function memory or programmable read-only system that produces a corrected gray-level value from inputs (gamma correction).(Ref. 4) In many cases, linear behavior is not necessarily desired, and contrast enhancement may be included at later stages of processing. As a less precise but simpler and more rapid technique, position-dependent correction can be applied to many adjacent pixels simultaneously. This avoids excessive hardware; however, care must be taken to avoid blockiness. A general circular symmetry is useful for this application because the general two-dimensional x, y variation is reduced to a single radial variable.

5.2 IMAGE REGISTRATION

After the geometrical and intensity non-linearities have been sequentially corrected to their required accuracies, the sensor information goes to a registration computer which determines the amount of misregistration and supplies signals to other systems for correction. Some of the possible sources of misregistration are identified here and possible correction techniques are described.

5.2.1 Sources of Misregistration

In typical systems, several types of misregistration sources are usually present. In general, it is possible to sequentially correct for many

[3] A. A. Sawchuk, "Real-Time Correction of Intensity Nonlinearities in Imaging Systems," IEEE Transactions on Computers, vol. C-26, January 1977.

[4] A. R. Colgan, "Integrated Cockpit Display System," Tech. Report AFAL-TR-73-50, Air Force Avionics Laboratory, (AFAL/AAA), Wright-Patterson Air Force Base, Ohio 45433, January 1973.

of them because none of them interact. It is assumed that geometrical and intensity nonlinearities, which are particularly dependent on the individual sensors and do not generally interact, have already been corrected to a degree consistent with acceptable tolerances for that sensor and system application.

One problem in image registration is that the two images to be registered are similar, but not identical, representations of the same general scene. Thus, registration is possible only if there are features of both images that are sufficiently identical to be matched. While gray scale values in LLLTV and FLIR images will not be the same, certain dominant features such as roads, rivers, man-made structures, etc., should be apparent from each image. With this correspondence, it is possible to estimate other residual types of misregistration. The problem becomes more difficult when registering radar and FLIR or radar and optical images. In these cases, few features, other than a river or a characteristic pattern such as an airstrip, may be readily discernible in each. However, the fact that both sensors are imaging the same scene, within the limitations of pointing accuracy, should facilitate the task.

Sensor noise or processing peculiarities (such as translations due to processed doppler) may prove to be a limiting factor in the performance of image registration systems, especially at very low signal levels. Other signal processing and filtering should be used to make the video input and geometric and brightness corrections prior to the registration computer as noise-free as possible.

If there are magnification differences between various sensors, an object may have a different size within each scene. Even if optical magnification is controlled, there may be electrical magnification differences between scanners. The effect could also be dynamic if zoom capabilities were included in the system.

There may be a horizontal or vertical translation difference between objects in two frames. This could result from mechanical misalignment or electrical deflection drift.

Images may also have a rotational misalignment due to mechanical errors, different degrees or orders of freedom of the sensor gimbals, motion of the sensor mounts, or electrical problems.

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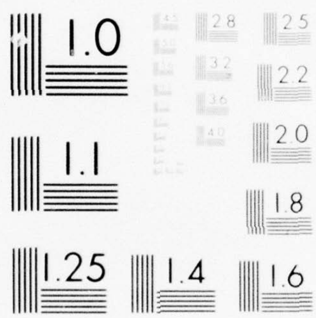

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

5.2.2 Determination of Registration Errors

In attempting to compile the total misregistration from all sources, it is important to separate the static effects, which may be compensated in advance, from other effects. Gross translational and rotational differences may be removed by calibration, while magnification differences or other small errors can be removed electronically in real-time. Many of the registration errors will be relatively small, perhaps on the order of a few picture elements (pixels) at most. This will greatly reduce the search time and computational effort required.

There are several techniques available for determining the misregistration between image pairs.(Ref. 5-8) Horizontal or vertical translation differences are the easiest to find, because they can be determined by shifting techniques on the rectangular picture grid. Two major methods of comparison are by statistical correlation and sequential detection. The sequential methods are much faster at eliminating mismatches because not every image point need be tested. Finding magnification and rotational differences is much more difficult, because of the rectangular sampling grid and the necessity of performing these distortions on the images to be registered when searching for a match. Some techniques involving transforms have been developed which tend to simplify this problem.(Ref. 9, 10)

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[5] J. G. Kawamina, "Automatic Recognition of Changes in Urban Development from Aerial Photography," IEEE Trans. Systems, Man and Cybernetics, vol. SMC-1, 1971, p. 230.

[6] R. L. Lillestrand, "Techniques for Change Detection," IEEE Transactions on Computers, vol. C-21, 1972, p. 654.

[7] D. I. Bamea and H. F. Siberman, "A Class of Algorithms for Fast Digital Image Registration," IEEE Transactions on Computers, vol. C-21, Feb. 1972, pp. 179-186.

[8] W. K. Pratt, "Correlation Techniques of Image Registration," IEEE Transactions Aerospace and Electronic Systems.

[9] H. K. Ramapriyan, "A Multi-level Approach to Sequential Detection of Pictorial Features," IEEE Transactions on Computers, vol. C-25, Jan. 1976, pp. 66-78.

[10] E. L. Hall, "Almost Uniform Distributions for Computer Image Enhancement," IEEE Transactions on Computers, vol. C-23, Feb. 1974, pp. 207-208.

There are several correlation systems in development at Hughes Aircraft Company which can be used to perform the registration error computation. An area video correlator has been developed for increasing the accuracy of target handoff from one onboard sensor to another, or to a missile sensor. This system can be used to correlate several types of sensor video: FLIR with FLIR, TV with TV, and FLIR with TV. In addition, samples of radar and FLIR imagery have been successfully correlated, indicating that the technique can be extended to be applicable to general FLIR and high resolution radar video.

Although the area correlator is a unique and straightforward design, it may be possible to utilize an even simpler device such as an n-line correlator to determine the image registration errors. This kind of correlator determines translational errors between two sensor images with respect to a single common image reference point. It is known that the n-line correlator is somewhat insensitive to rotational errors. However, by selecting two reference image points and performing an n-line correlation at each, common vectors in the two image fields can be identified and the angle between them measured. This angle is the rotational difference, which can then be applied to correct the error. Similarly, comparison of the vector lengths gives the magnification difference. Thus, by using a relatively simple boresight correlator and making measurements on several image points, the four remaining major registration errors, X and Y translation, rotation, and magnification, may be determined.

5.2.3 Correction for Misregistration

Once the misregistration parameters are identified, they are fed back to the preprocessing system. A microprocessor-controlled modular digital scan converter (MDSC) system can easily perform translational corrections and magnification corrections based on the inputs from the registration computer. The horizontal/vertical shifts are used to offset the readout, and the magnification correction is used as input to the scan line matching system. The difficult operation is rotational correction, which would be very complex if performed in the MDSC due to the non-rectangular readout which would be required. The rotational correction could be applied directly to the sensor electrically or mechanically. The same technique could be used with a zoom control for feedback magnification correction.

For these two types of errors, correction by sensor realignment seems to be the simplest and most cost-effective. However, for low update rate sensors or data, the MDSC can accomplish these corrections adequately.

5.3 IMAGE PROCESSING

After format conversion and registration are accomplished, there are a number of different image processing techniques that can be applied to the images before they are combined for presentation to the observer. A limited number of these possible techniques are considered here, including:

- Gain control
- Thresholding of one video signal and placement of only the highlights on the second video image.
- Thresholding of one video signal at either saturation level or minimum intensity level such that the second sensor video can be inserted in these regions.
- Sampling of the scene modulation in one sensor image and insertion of second sensor video in areas of low detail.
- Edge enhancement of one video image and placement of only the outlines on the second video image.
- Level slicing for outlining regions with a common brightness or color coding regions with a common brightness.
- Advanced image analysis techniques such as change detection to detect moving objects and pattern recognition to recognize types of targets.

The individual and relative values of these processing techniques for target acquisition are yet to be determined. Human factors measurements are needed to quantify the amount of performance improvement, if any, that could be achieved with the use of these operations. While all these operations are considered in the general system for the sake of completeness, in practice only one or two may be selected for incorporation in an operational system. Note, however, that Section 6.0 will show that most of the operations, other than change detection and pattern recognition, are sufficiently simple to implement such that a highly flexible general system is quite feasible.

Many of the above image processing functions are most applicable to TV, FLIR, or other images with large gray level content. Several of these techniques are not applicable to radar, such as modulation sampling

or thresholding for fill-in with video from another sensor. Selection of the functions can be manual or programmed to be semiautomatic or automatic with pilot override. Under severe task loading conditions, little or no operator involvement should be required, and the selection of processing and display techniques should be as automated as possible.

Some of the processing techniques ideally assume the availability of a high resolution color display in the ultimate system, although it is realized that such displays are in the development stage and not yet standard aircraft equipment. It is anticipated that the use of false color to distinguish between multisensor information combined on a single display may facilitate the perception and utilization of that information. However, most of the enhancement techniques can also be effected on a monochrome display. The improvement in performance associated with using a multicolor display, compared to a monochrome display, should be determined by means of a human factors laboratory evaluation.

The various processing features which were considered and their possible enhancement of the visual display are described as follows.

5.3.1 Gain and Function Memory

A gain control or contrast enhancement can be automated to provide a maximum dynamic range without clipping. Implementation is by digital table lookup. The gain control can be expanded to include a look-up table mapping function to correct for nonlinear intensity distortions described in Section 5.1. If a broad range of gray values is desired, a real-time histogram measurement system could be incorporated to keep track of the gray level distribution. Then, a nonlinear mapping could be applied to pixels to uniformly distribute the values over the display dynamic range (histogram equalization).

5.3.2 Thresholding

This nonlinear function determines the level at which signals from one sensor will be clipped and overlaid as highlight data on another sensor image. For example, when radar is the primary sensor display, the FLIR video could be thresholded such that only the hot spots are superimposed on the radar image as a target cuing or verification mechanism.

Thresholding is also useful for radar glint information. These radar glints could be placed on a FLIR display to cue the pilot to cold vehicles, for example, which have no strong thermal signature or as verification of hot metal objects. When superimposing FLIR and TV, the thresholded FLIR hot spots could be placed on the TV display.

Thresholding for "fill-in" can be used with FLIR and TV as a means of "extending" the display dynamic range in the following manner. The FLIR video can be thresholded such that all FLIR information above a certain level (within a saturated area) is replaced by TV information. An alternative is to threshold the TV video such that all TV information below a certain level (dark area) is replaced by FLIR information.

5.3.3 Scene Modulation Sampling

Thresholding can be applied to image features other than luminance. An "activity" or modulation measure can be computed in a small moving window of pixels (in both sensor scenes) by measuring signal variance about the mean. If this variance exceeds a threshold, signifying a lack of detail in that area of an image, data from another sensor can be inserted. Such a system can thus provide the maximum detail from several operational sensors and may be particularly suitable for synchronized FLIR and TV combinations.

5.3.4 Edge Enhancement

Linear high-frequency emphasis or differentiation operators are useful for enhancing edges within an image and thus assisting in shape recognition. Edges are sometimes displayed as binary pictures in place of or together with the continuous tone scene. Because they are linear, however, they are somewhat error-prone and noisy. Recently, several higher performance edge operators have been described which are highly nonlinear. One of the simplest, yet effective, is called the Roberts operator. The Roberts edge detector works on a 2 x 2 array of pixels. Denoting the brightness of two adjacent pixels in the top image line by A and B and two pixels just below in the next line by C and D, the Roberts operator output is

$$E = \mathrm{th}\left\{\left|A - D\right| + \left|B - C\right|\right\}$$

where "th$\{\cdot\}$ " denotes a threshold. The absolute values are easy to compute, and the computation takes only two lines of image storage. Other versions of edge operations are available. Some operate in a 3 x 3 array, and others involve complicated edge fitting in the Fourier domain.

Edges could be displayed in another color on the same image or on a second sensor image, or could be used to sharpen the edges in a continuous tone picture. Even the best edge detectors suffer from noise, which leads to fake edge points and gaps in object outlines. More sophisticated (and computationally difficult) techniques involve boundary tracing, or connections between edges to better outline objects and areas of interest. More study is necessary to determine the relative advantages (if any) of these highly sophisticated techniques for shape recognition.

5.3.5 Level Slicing

This technique can be used to outline objects with a common brightness. Often this display technique is made interactive, and the "sliced" regions are displayed at high luminance or in a different color. By providing multiple thresholds, a range of gray level values can be color-coded. For example, the sensor dynamic range could be divided into three regions and a different color assigned to each. In the extreme, every level of gray can be made a different color. This false color technique makes use of the fact that color changes can be more easily discriminated than small gray level changes and thus causes subtle gray level changes to stand out.

5.3.6 Change Detection

This feature would use frame-to-frame differences for the detection of moving objects. By detecting image differences or using more sophisticated correlation techniques, movement in a fixed time period could be identified. Since most moving objects in a scene are man-made, this cuing information could be extremely useful to the observer for target acquisition.

5.3.7 Automatic Feature Extraction and Target Cuing

High-level image processing algorithms can be used to analyze component parts of the scene for feature extraction and pattern recognition of roads, waterways, bridges, structures, vehicles, etc. The location of

these features or objects might be indicated by a complex graphics or symbol overlay on the display as a target cuing mechanism. Many of these techniques for object pattern recognition and target cuing are presently in the research stage. The recognition and extraction of complex features is a difficult task requiring a great deal of computation. The decision process consists of several levels: 1) feature extraction (such as edges, texture, etc.), 2) combination of these features into higher level primitives (shape, outlines, segments of objects), and 3) interpretation of the primitives in terms of pattern recognition. Such a system would be valuable for reducing the observer's workload directing him to critical areas on the display. It is expected that substantial progress in image analysis and understanding will be made in the future and that the techniques developed will be applied to display systems. Thus, provisions for display of the extracted data should be made in the multi-sensor display system.

5.4 COMBINING IMAGES FOR DISPLAY

This section describes possible techniques for combining images from two or more sensors on a single display. The selection of an optimum combining technique will require a human factors experimental evaluation of the candidates listed and will undoubtedly depend on the types of imagery being mixed.

5.4.1 Arithmetic

A simple method of combining multiple sensors is to use a high speed arithmetic unit which produces a single output at each pixel from multiple inputs. A fixed function could be a weighted arithmetic or geometrical mean, or a nonlinear (logarithmic) function which would attempt to present a maximum useful dynamic range to the observer. Weights on the means could be fixed or operator-variable, or could be automatically varied by an activity threshold circuit.

5.4.2 Interlace

A more direct method avoids the arithmetic combination and interlaces two frames. This technique would require additional display resolution and would provide the same visual effect as averaging.

5.4.3 Interframe

A flicker mode (alternate frame function) could be used to switch from one sensor to another at a predetermined rate or at a threshold controllable level. Although this type of switching is straightforward, the flicker may be distracting at very low rates; at high rates (>20 frames/second), the human visual system would integrate the frames.

5.4.4 Local Area Insertion

The insertion of one sensor image (typically narrow field of view) within a second sensor image (wide field of view) represents a possible technique for maintaining WFOV context while attempting to acquire a target with a NFOV sensor. An example is the designation of a possible target on the radar display and the subsequent display of a NFOV FLIR image centered at the designated point while a radar image "picture frame" border is maintained for context. This facilitates the return to the radar display for redesignation, if the NFOV FLIR scene does not contain the desired target. The insertion boundaries may be manually selected or automatically selected by an image cuing system.

5.4.5 Stereo

Another possible alternative would make use of the height discrimination ability of stereo vision. Stereo can be achieved by two separate displays or split screen on a single display with appropriate optics (goggles or filters) to provide separate images for each eye. With only a monochrome system, the height variable could provide graphics, or highlights or glints from one sensor could be displayed as a height variable on top of a continuous tone background. The stereo possibility has received little attention in the past, primarily due to the complexity, but it may be advantageous to reevaluate some of the methods in the light of present-day technology.

5.4.6 Multicolor

Although simultaneous presentations could be combined on a black/white or single color display, the use of false color coding may assist in differentiating information or imagery from several sources. It would thus be desirable to associate a particular color with highlight data from a

particular sensor, such as green with radar glints, red with FLIR hot spots and blue with TV bright spots.

It is anticipated that primary sensor or background imagery would probably be displayed in a comfortable broadband white or yellow-green. For example, radar imagery could be displayed in green while FLIR hot spots or edge-enhanced features could be overlaid in red. FLIR imagery could be displayed in broadband white while radar glints are overlaid in green or TV data (object outlines, thresholded bright areas, high-detail areas for FLIR fill-in) are displayed in blue. Color can also be useful when overlaying graphics and symbology on continuous gray level imagery.

As described previously, false color coding of gray level "slices" can assist in enhancing small gray level changes. Another possibility which may merit future consideration is the false coloring of the output from high level feature detectors (based on texture, gray shade, edges, etc.). Thus, for example, broad regions of water (identifiable through gray level, shape and texture characteristics) might be colored blue, so that some of the interpretive processing typically done by the human visual system is now performed by the processor/display. In the multisensor application, false color could be used to color code regions identified from several sensors by a pattern classifier. In this way, unique spectral signatures acquired from several sensor bands could be used to present a unique color to the observer. With training, an observer might be able to discriminate among very subtle object differences based on all the sensor inputs.

5.5 CONCLUSIONS

The various processing operations associated with accepting two (or more) disparate sensor video and combining them on a single display have been discussed in this section. Four general functions have been considered:

1. Preprocessing operations involving coordinate transformation and line scan matching to make the two video format-compatible,
2. Determination of the misregistration between the two images and possible correction methods,
3. A shopping list of image processing or enhancing techniques for extracting highlight information from one sensor video and displaying it on a second sensor image.
4. A shopping list of mixing techniques, including the use of false color coding, for effectively combining information from two sensors on one display surface.

A sizable number of possible processing operations have been included here for completeness and for indication of what could be accomplished if desired. In practice, however, an operational system may require a very limited number of these operations to achieve significant performance improvement. Fine corrections may not be required for local geometric distortions or brightness nonlinearities. Strict tolerances may not be required for image registration; in fact, slight misregistration of images may actually enhance target acquisition. As few as one or two simple image enhancement techniques for extracting salient information from one sensor for display on a second sensor image may enable targets to be acquired at longer range or in shorter time. False color coding of highlight information may be an effective means of assisting the operator to discriminate between sensor inputs.

It is evident that an experimental evaluation of these parameters is needed to establish minimum system requirements and to quantify changes in operator performance as a function of correction tolerances, enhancing operations, and color combinations.

It is also evident that all of the processing operations selected for incorporation in an operational system must be as automated as possible. On a prebriefed mission, the sequencing of simultaneous presentations can be preselected, typically as a function of mission phase. Also, the processing operations associated with each sequential simultaneous presentation can be preprogrammed or made highly adaptive and automatic. Thus, operator interaction and task load can be minimized, while allowing for operator override in all cases.

6.0 IMPLEMENTATION CONSIDERATIONS AND TYPICAL SYSTEM OPERATION

This section discusses the conceptual implementation of a general simultaneous presentation system in terms of hardware and processing requirements, and describes typical system operation for several sensor combinations.

The most promising simultaneous presentation candidates which emerged from Section 4.0 can be summarized as:

1. Real-time sensor image (radar) and stored cartography.
2. Real-time sensor image (radar) and stored or data-linked target imagery, and
3. Two real-time sensor images (radar and FLIR, FLIR and TV, etc.).

The most complex case, i.e., case 3, was addressed in Section 5.0, where a multiplicity of processing operations, both required and optional, were considered for the simultaneous display of two real-time sensors. These same considerations could be readily applied to the two simpler cases, 1 and 2, involving a real-time sensor and stored/data-linked imagery or cartography.

As the next logical step, the complexity of implementing the most difficult case, the combination of two real-time sensors, will be considered. This section does the following:

1. Examines the pertinent avionics equipment which may already be onboard the aircraft,
2. Describes possible implementation techniques for the various processing operations identified in Section 5.0, both necessary and optional, thus resulting in a general system implementation,
3. Describes a typical system operation for two complex examples, i.e., radar plus FLIR and FLIR plus TV, and
4. Examines the key elements from the general system implementation which would be required to implement each of the promising simultaneous presentations identified in Section 4.0.

A concentrated effort has been made in the implementation considerations to make use of hardware which is presently available or in development at Hughes Aircraft Company. This use of state-of-the-art equipment

whose capabilities and interfaces are fully understood was considered preferable for sizing the mechanization complexity, as compared to a more general analysis of possible alternate implementation. Thus, the following sequential description of the implementation of each function in the general system is based on Hughes' related engineering experience with well-understood technology.

6.1 ONBOARD SENSORS/PROCESSORS

Several promising combinations of primary sensors and supplementary sensors or stored data have been identified for simultaneous presentation on a multipurpose display as a function of mission phase. Before estimating the complexity of implementing these combinations, let us reexamine the sensors and processing equipment which are assumed to be onboard the aircraft and the manner in which they interface for each of the selected combinations or mission phases.

The baseline sensors, data sources and associated processors considered onboard correspond to the various subsystems which comprise the F-18 avionics suite. (This suite was selected as representative of an advanced, high performance, single-seat attack aircraft.) Figure 18 shows the functional interfacing of these subsystems for key mission phases. The corresponding primary and secondary sensors or data sources identified for these phases are as follows.

- During cruise-out, as shown in Figure 18a, the primary sensor is the radar for navigation purposes, supplemented by a priori data such as stored cartography, stored target and threat data, and threats detected by onboard warning receivers.
- Preliminary target acquisition may be achieved during cruise and before descent for run-in. As represented in Figure 18b, the radar again is the primary sensor and can be supplemented by a priori data such as stored target imagery, by stored and real-time warning information, and possibly by hot spot cuing indications from a high performance FLIR.
- Stand-off range pop-up can also be represented by Figure 18b. The primary sensor in this case depends on the range. For slant ranges greater than 50,000 feet, radar is typically the primary sensor, possibly supplemented by FLIR hot spots. At ranges less than 50,000 feet, FLIR is the primary sensor, possibly supplemented by radar glints.
- At minimum range pop-up, as shown in Figure 18c, the FLIR is typically the primary source for target reacquisition and weapon delivery, unless severe weather conditions prevail. The possible

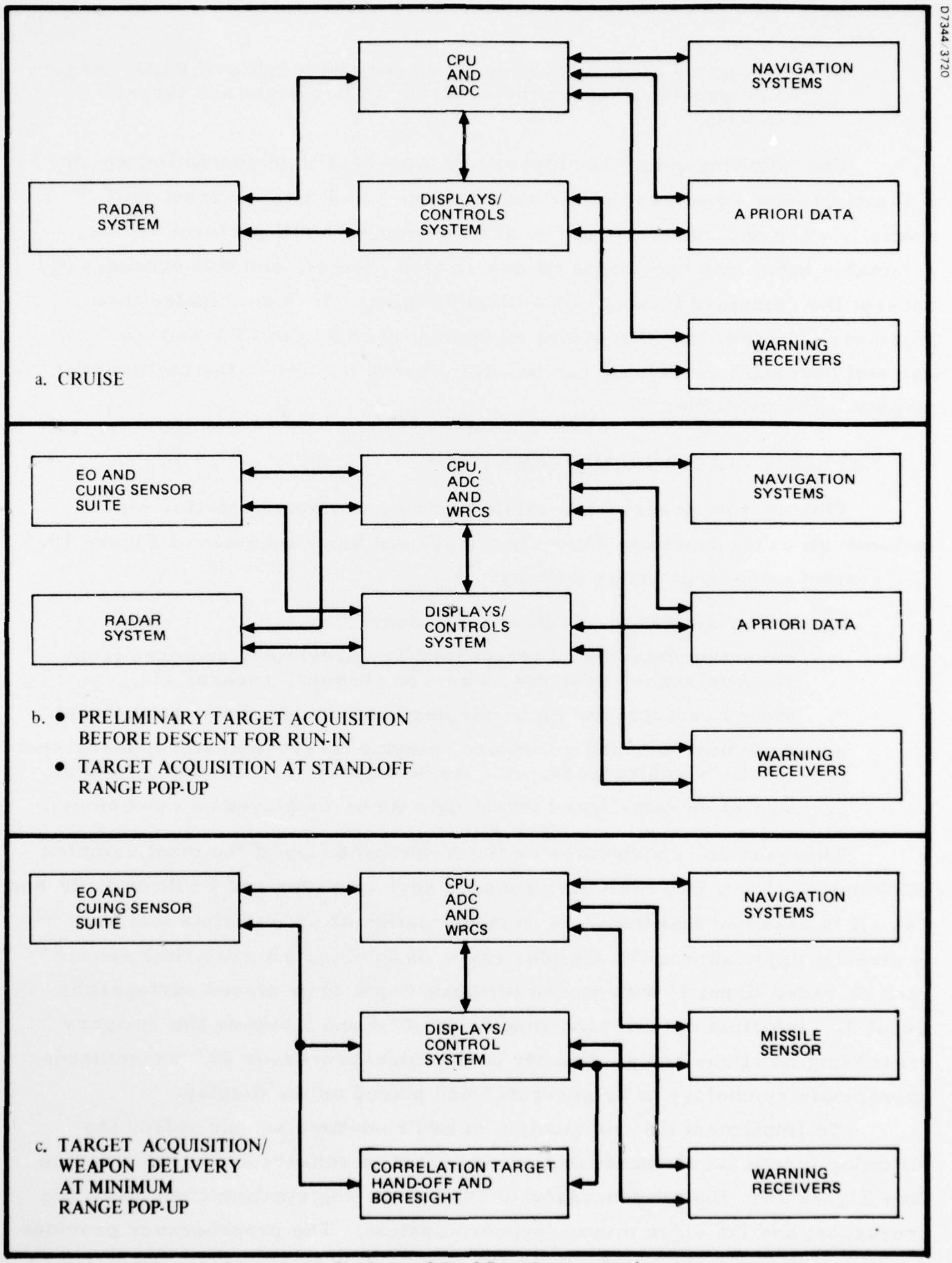


Figure 18. Interfacing of F-18 avionics subsystems as a function of mission phase.

correlation of missile sensor imagery with onboard FLIR imagery could greatly improve the accuracy of boresight and target hand-off.

The following subsection describes a general implementation which will accept inputs from any of the above sensors and data sources, will spatially warp and register any two desired images, will perform various selectable enhancing operations on one or both images, and will subsequently present the combined imagery on a single display. It is anticipated that portions of the onboard processing equipment such as the CPU and the optional boresight correlator can be time-shared for use in the multisensor display implementation.

6.2 IMPLEMENTATION CONSIDERATIONS

This section describes possible methods of implementation which includes all of the functions shown in the system block diagram of Figure 19. The system can accept inputs such as:

1. real-time radar, FLIR and TV video,
2. stored or data-linked target imagery previously acquired from reconnaissance cameras, infrared sensors, radars, etc.,
3. stored cartography (to be displayed as graphics and symbology),
4. real-time warning receivers, moving target indicators, laser spot trackers and rangers, etc. (to be displayed as symbology), and
5. stored or data-linked threat data (to be displayed as symbology).

This section concentrates on the implementation of the most complex combination, i.e., two real-time sensors such as radar and FLIR or FLIR and TV. It is assumed that the same implementation which satisfies this case is directly applicable to the simpler cases of combining a real-time sensor such as radar (Input 1) with stored imagery (Input 2) or stored cartography (Input 3). Information corresponding to Inputs 4 and 5 bypass the imagery processing functions and go directly to the microprocessor which commands appropriate symbology to be generated and placed on the display.

To implement the combination of two real-time sensor video, the following functional elements are needed between sensors and display device (see Figure 19): the preprocessor (including the registration computer); the processor; and the video mixing/synchronization. The preprocessor provides the formatting necessary to convert the sensor data to common computational and display parameters and also determines the errors in image translation,

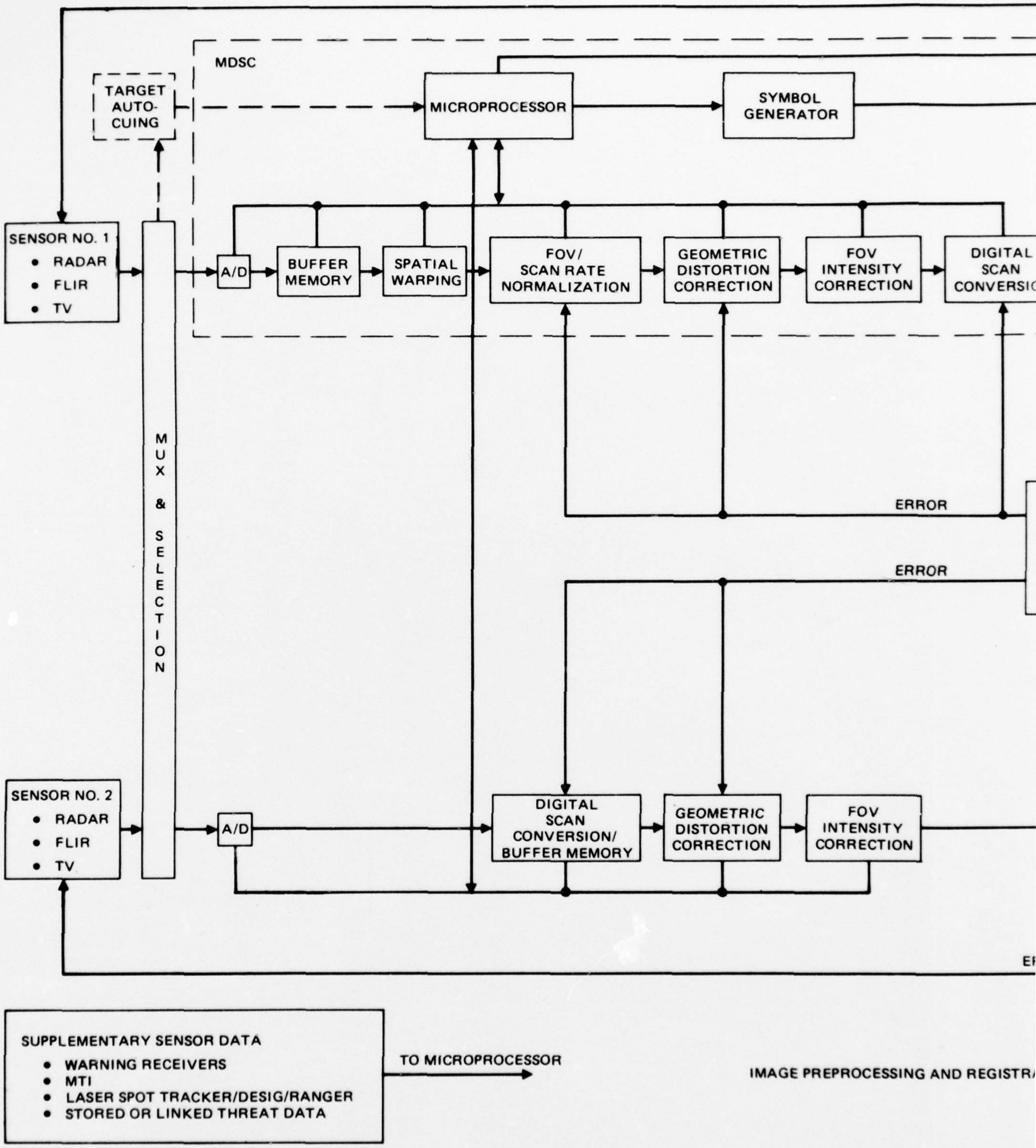


IMAGE PREPROCESSING AND REGISTR

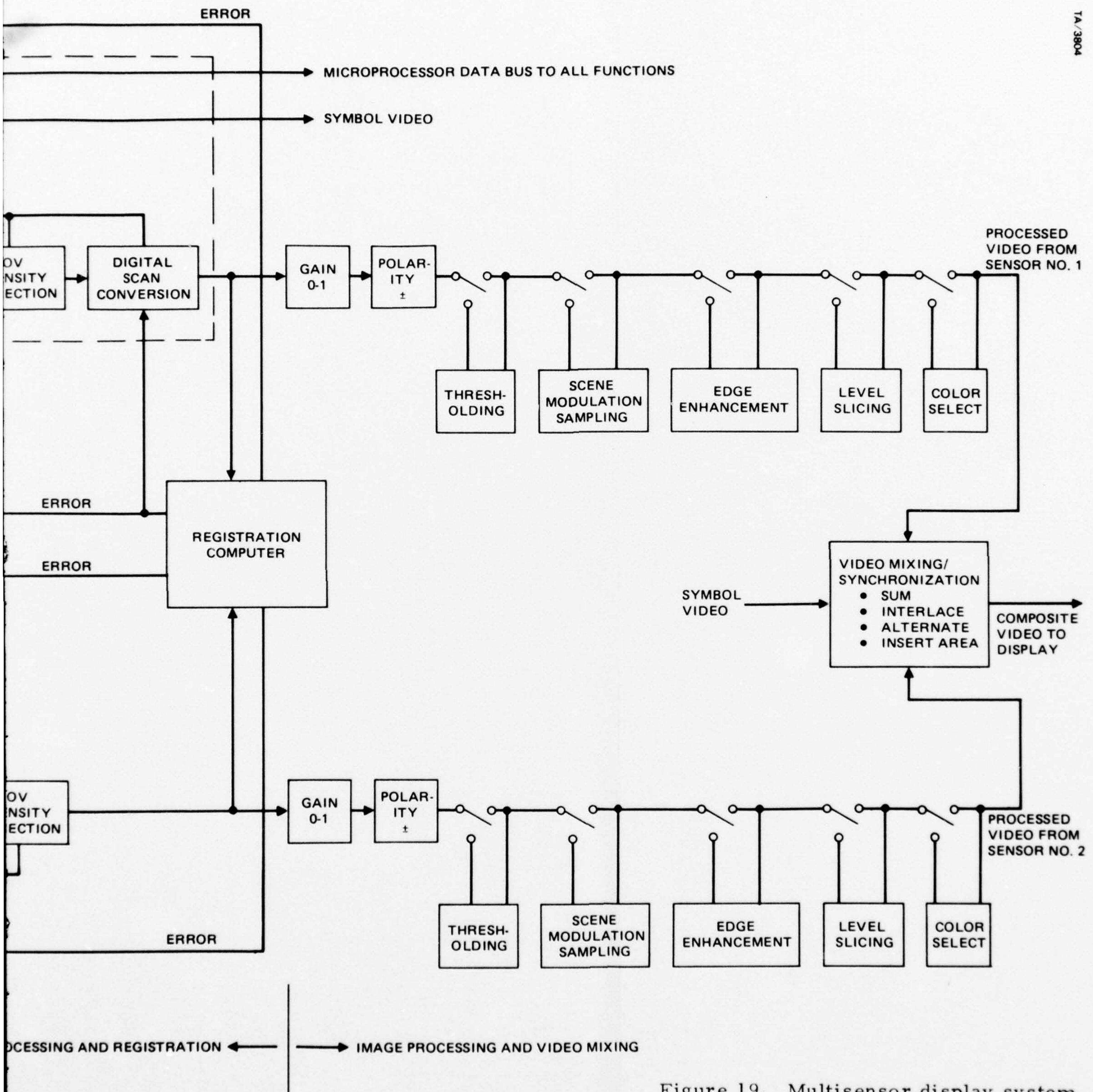


Figure 19. Multisensor display system block diagram.

rotation and magnification for registration corrections. The processor function consists of the processing operations which are performed on the sensor video for image enhancing or cuing purposes. (Figure 19 shows a shopping list of processing operations which could implemented.) The video mixing and synchronization mixes the processed video from the radar, FLIR, and TV sensors and generates a composite video output. All the functions are controlled by a microprocessor.

A sizeable number of possible correction functions, processing operations, and mixing techniques are included in the general system of Figure 19 for the sake of completeness. In practice, however, an operational system will undoubtedly implement only a limited number corresponding to the desired flexibility, required accuracy, and permissable system complexity of the intended application.

The following subsections present a more detailed description of the hardware needed for function implementation.

6.2.1 Preprocessor/Registration Computer

The preprocessor function includes the analog to digital conversion, automatic boresighting of the sensors, the radar scan conversion to TV scan line format, and the warping of the EO imagery from an azimuth/elevation format to a radar azimuth/range format or the inverse. The preprocessor also includes a programmable symbol generator for overlaying symbols on sensor video.

Digital processing is preferred over analog processing because of the necessity for flexibility and control. Another advantage of digital processing is stability and repeatability in an experimental implementation, so that subsequent evaluation can be well established. The digital implementation of the processor functions is easily interfaced with the control microprocessor to provide control of all internal variables, i.e., varying gain, threshold, and processor functions implemented. However, it should be noted that rapid advances are being made in analog circuit technology (e.g., charge coupled devices) and the actual mechanization should be selected at the time of development.

The analog to digital conversion of the video data is provided for the radar, FLIR, and TV. Since only two imaging sensors are displayed at any

time, only two A/D converters are required. One A/D converter is provided internally in the modular digital scan converter (MDSC) which will be described shortly. A second A/D is provided and is multiplexed with the MDSC A/D to provide two digitized sensor inputs. The multiplexing functions are provided for the A/D converter, registration computer or boresight correlator, and the MDSC.

The boresight correlator (registration computer) corrects azimuth and elevation boresight errors between two sensors, one sensor acting as the reference sensor. Since only two imaging sensors are displayed simultaneously, only one boresight correlator is required with multiplexed inputs. Two versions of boresight correlator have been developed at Hughes Aircraft Company. One is of minimal complexity but is relatively insensitive to rotational errors between sensors. The other implementation, which is capable of computing rotational errors, is a factor of three more complex. Both boresight correlators operate by crosscorrelation of the processed videos.

The boresight offset between the reference sensor and the second input video source is corrected in the MDSC. The MDSC provides horizontal element and vertical line delays to adjust the offset between the two selected sensors. Assuming the use of the less complex correlator, rotational errors may be corrected by correlating several points in the two sensor images and then calculating the rotational error in the microprocessor. Video rotation cannot be performed in real time in the MDSC without difficulty. Therefore, the rotational error should be applied directly to the sensor orientation to compensate for the error if high update rate sensors are involved. If stored imagery and low update rate sensors are used, then the correction can be applied at the MDSC. In addition to determining rotation error, correlation at several points also allows magnification or FOV errors to be computed and then corrected in the MDSC.

The radar scan conversion converts the radar-type raster scans at low update rates to a TV format at TV update rates. A version of the MDSC developed under contract to the Air Force Avionics Laboratory, is ideally suited to this application. The MDSC is controlled by a microprocessor and can provide appropriate flexibility and system control. The warping of an EO azimuth/elevation format to the radar azimuth/range format can be achieved by using the appropriate scan converter memory

loading algorithm. Furthermore, the scan converter can perform the boresight correlation offset correction as well as FOV compensation and line rate matching.

If the two sensors operate at different TV line rates (say, 525 versus 875 lines), the sensor video can be loaded into the scan converter in one line standard and read out in another. Therefore, the one sensor video can be matched in line rate to the other. By passing the data through the scan converter memory, the horizontal and vertical axis can be scaled to adjust the one sensor FOV to match the reference sensor. The boresight offset can be used to offset the center position of the video in the scan converter memory to compensate for the boresight error.

Correction for intensity nonlinearities and shading can be provided digitally via programmable read only memory (PROM), to provide a table lookup mapping.

The microprocessor bidirectional serial data bus can be used to provide system mode control. The serial bus would control the processing functions employed.

A symbol generator can also be included in the system. The symbol generator is programmable and controlled by the microprocessor. Based on inputs from supplementary sensors such as warning receivers, MTI, laser spot tracker/designator/ranger, and stored or linked threat data, the microprocessor instructs the symbol generator to overlay symbology at appropriate positions on the sensor video display.

Provision can also be made for displaying the output of automatic target cuing devices which are presently in development. These sophisticated processors are being designed to detect and discriminate road, structure, and vehicle targets. When such a target has been detected, discriminated, and located, the required target type and position information can be transferred to the microprocessor. The microprocessor would then provide the symbol generator with the appropriate instructions to provide a symbolic overlay of the target. If a tank was detected, for example, the symbol generator would display a coded symbol at the coordinates of the detected tank, overlaid perhaps on the FLIR sensor imagery.

6.2.2 Processor

The processor functions include: 1) video thresholding for placing sensor number 1 highlights on sensor number 2 video, or for inserting sensor number 1 video in saturated or dark areas of sensor number 2 imagery; 2) scene modulation sampling for inserting sensor number 1 video in low detail areas of sensor number 2; 3) edge enhancement for outlining single sensor video, or for overlaying outlines of sensor number 1 imagery on sensor number 2 imagery; 4) level slicing for outlining areas of constant brightness on a single sensor display, or for overlaying sensor number 1 outlines on sensor number 2 imagery; and 5) color selection for false coloring of each gray shade in a level-sliced image, or for color-coding the sensor information in each of the above 4 combinations. The microprocessor selects the function implementation as well as setup of control variables. Implementation of each technique is as follows:

Gain/Polarity

Gain control is provided digitally via PROM as a table look up multiply, as shown in Figure 20. The polarity is simply a multiplexing between the sensor data or its inverse.

Threshold

The threshold function, as shown in Figure 21, selects and compares the digitized sensor number 1 video with a threshold determined by the microprocessor. The threshold is subtracted from the sensor video to remove all video below (or above) the threshold from the sensor video.

For highlighting purposes, the video number 1 exceeding the threshold is outputted, with the remaining scanned data set to zero, and overlaid or suitably combined with sensor number 2 video.

For fill-in purposes, the microprocessor sets the threshold level such that video number 1 above a certain "dark" level is outputted and video number 2 "fills in" the areas below the thresholded levels. Or, video number 1 below a certain "white" level is outputted and video number 2 fills in the areas above that threshold level.

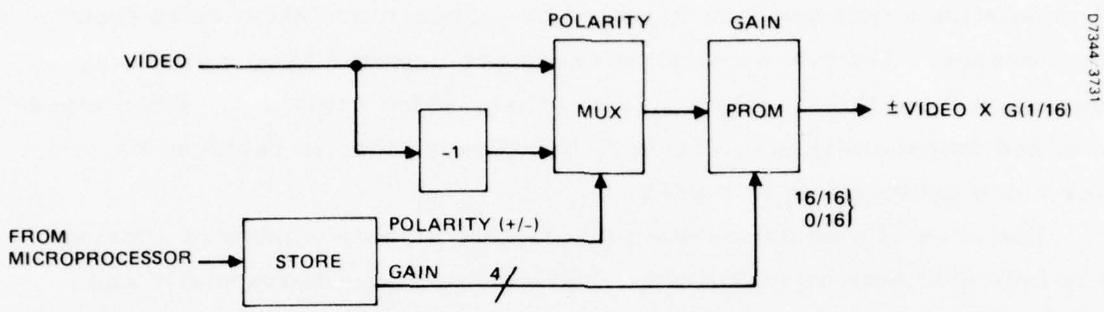


Figure 20. Polarity and gain control.

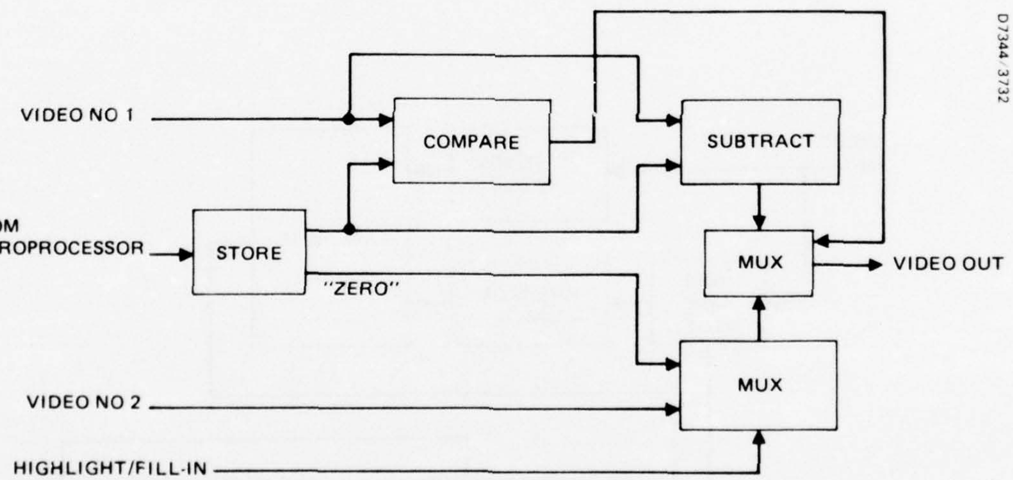


Figure 21. Threshold for highlighting or fill-in of dark/bright areas.

Scene Modulation Sampling

In this technique, the sensor video is sampled to determine modulation. Low modulation areas are then replaced by higher modulation video from another sensor. The low modulation areas are detected by accumulating the variation from the average value of sensor video number 1. When a predetermined threshold is not exceeded, the sensor video is replaced by sensor video number 2 in this area.

The area of modulation sampling is formed as a window of approximately four elements by four lines. The window slides horizontally and vertically through the display raster until the entire image is scanned. The low modulation replacement shown in Figure 22 accumulates the video from four elements of the present and past TV line. The accumulator adds the newest video element and subtracts the video four elements delayed. The two accumulators are summed to form the mean video within the window.

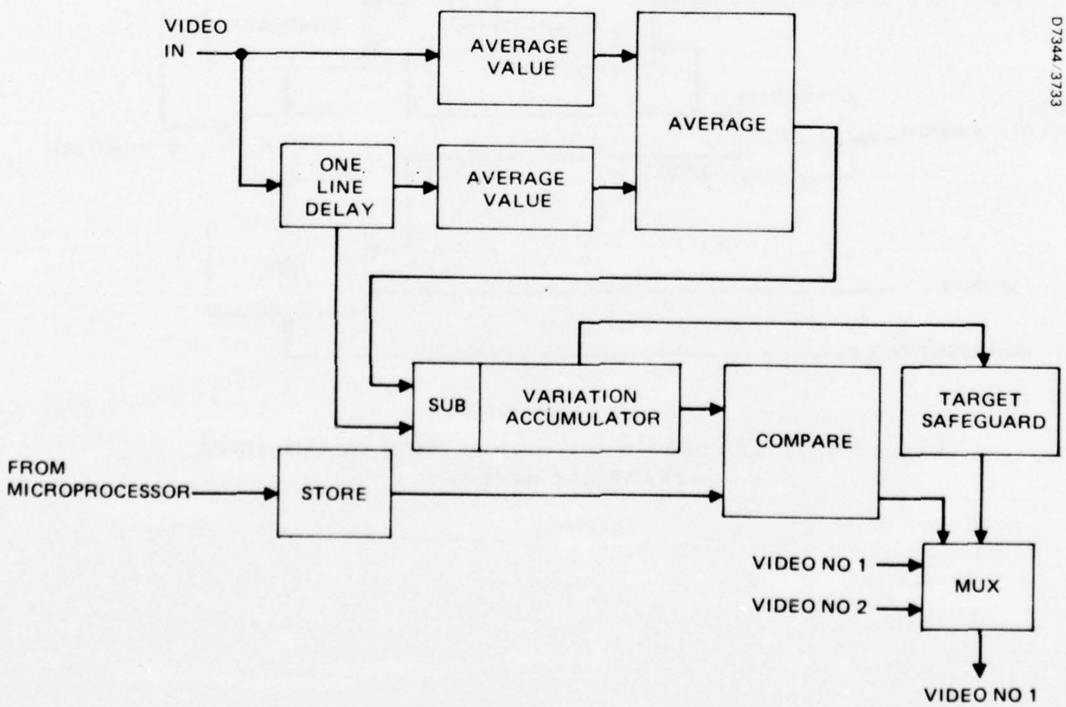


Figure 22. Scene modulation sampling for low modulation replacement.

The mean is subtracted from the value of the center element and the absolute value is accumulated to provide a measure of the modulation. The modulation factor is compared to a threshold controlled by the microprocessor, and the output video from another sensor is switched in when the threshold is not exceeded.

Another high threshold is set (by the microprocessor) to detect targets in low modulation areas. If the video minus the mean exceeds the higher threshold, the original video element is inserted into the second sensor video to indicate the detected target position. Thus, a reasonably failsafe circuit is provided to eliminate the loss of a peak target in a low modulation area.

Edge Enhancement

Edge enhancement is achieved by a differential operator which detects edges in the video scene. Using the Roberts operator described in Section 5. 3. 4, edge-like variations occurring horizontally, vertically, and diagonally are detected and the video gain is increased proportionally to the edge variation. This function results in the outlining of man-made features which are contained in the sensor video.

The edge enhancement function shown in Figure 23 forms a two-element by two-line sliding window The ROM performs a matrix multiply to detect horizontal and vertical boundaries Where boundaries are detected, the video gain is increased to enhance the edges. The microprocessor selects the amount of gain (or other function) applied to the edge regions.

Level Slicing

Level slicing requires that multiple thresholds be applied to the sensor video. To obtain false color, each amplitude slice must be encoded at a different color. As shown in Figure 24, the level slicing function compares the sensor video with multiple thresholds from the microprocessor. Each threshold forms a window which can be used to encode the video amplitude between thresholds into a different color. The threshold value is subtracted from the video to remove the bias from the output. A ROM multiply increases the gain of the windowed video to a full scale output. The output multiplexer selects between the thresholded video, normal video or a no-output condition.

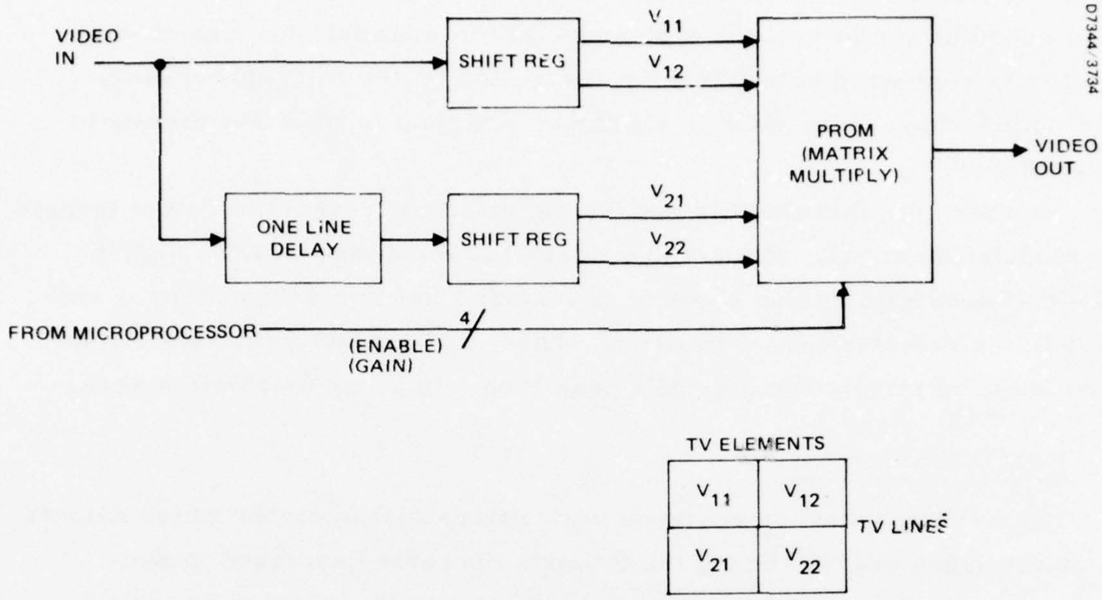


Figure 23. Edge enhancement.

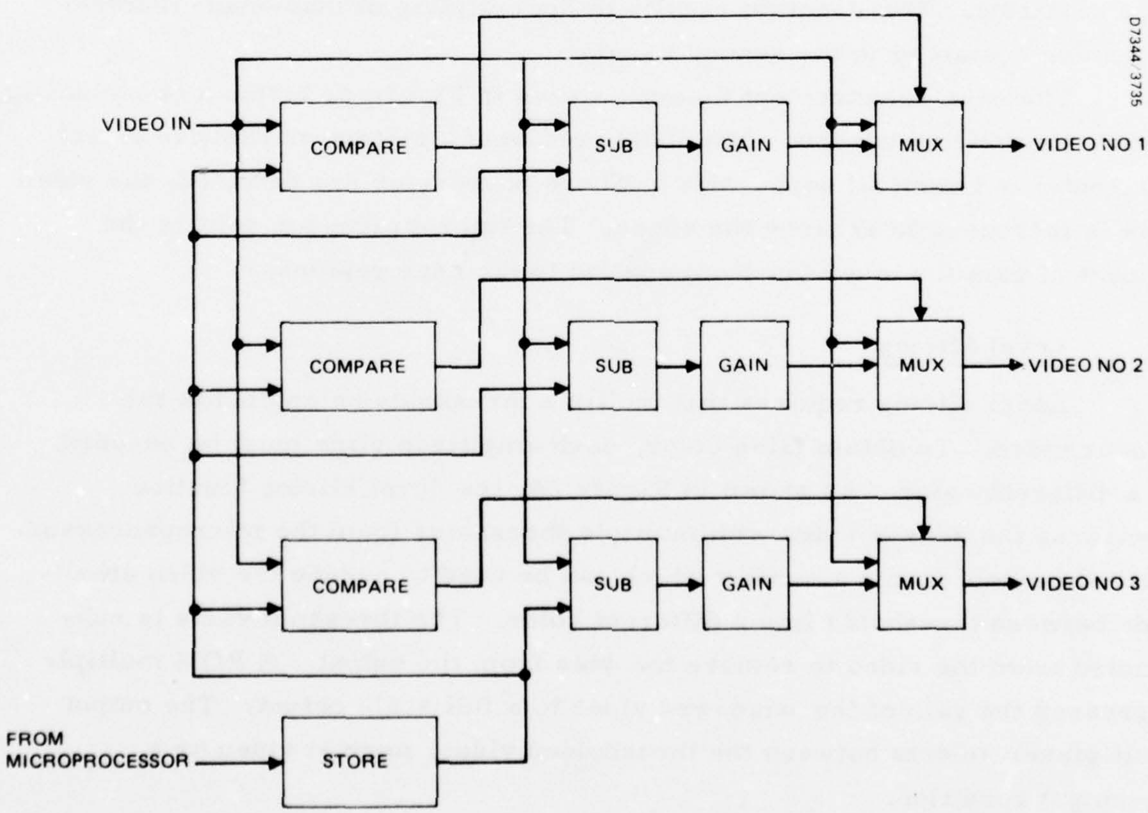


Figure 24. Level slicing.

False Color Select

The availability of color display allows each sensor output to be artifically encoded into a selected color output. The false color select function shown in Figure 25 encodes the sensor video to any or all video color outputs. The selection is under microprocessor control.

6.2.3 Video Combination

Possible combination techniques include summing the two video sources pixel by pixel, replacing video number 1 pixels with selected pixels from video number 2, interlacing the two videos, or alternating their presentation at a selectable rate.

In the alternation scheme, the function shown in Figure 26 switches from one sensor to another by multiplexing between the two sensors at an integer number of field times. The vertical sync is counted down and the microprocessor selects the appropriate frequency from the set of 60, 30, 15 and 7.5 Hertz.

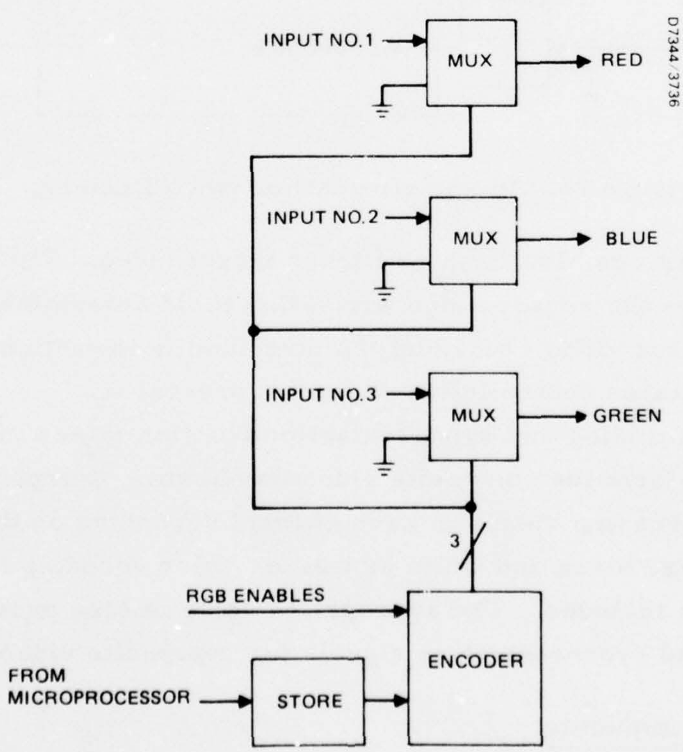


Figure 25. False color select.

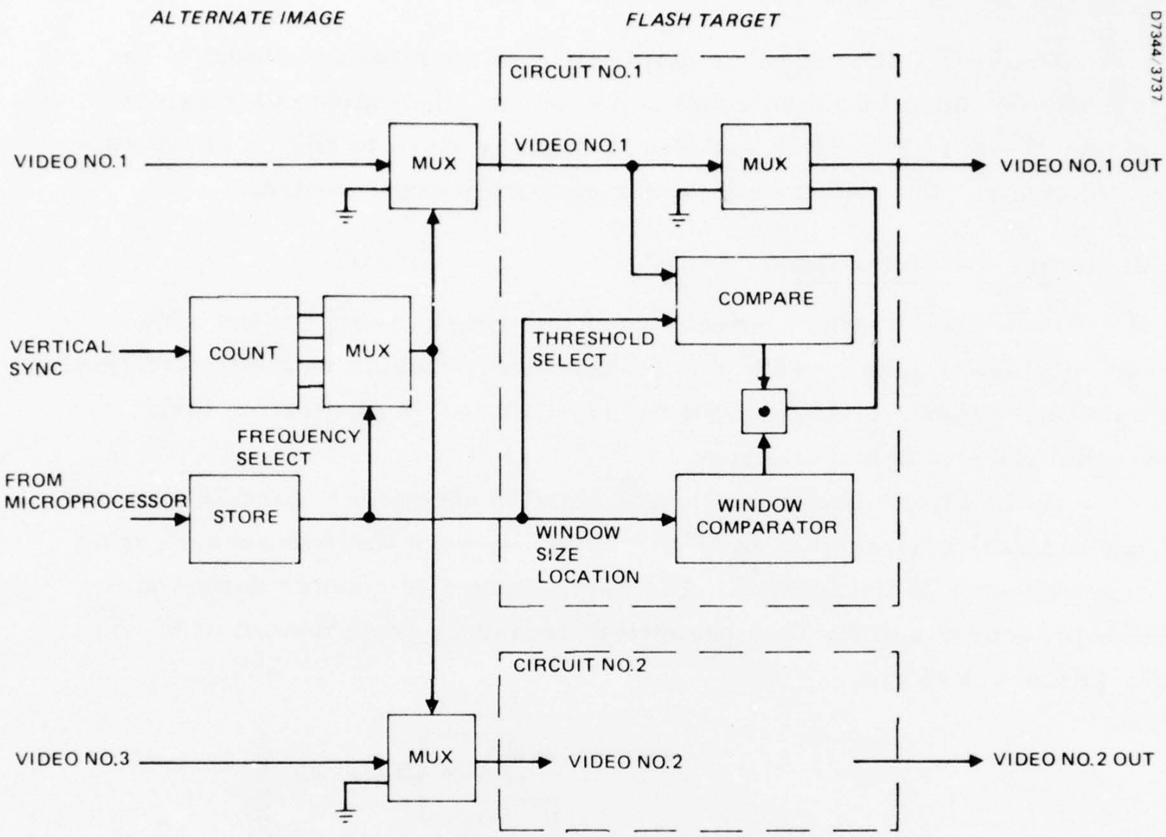


Figure 26. Image alternation/video flashing.

The circuit can also flash or flicker target video. The flashing function compares the sensor video with a threshold determined by the microprocessor. Sensor video exceeding the threshold is then flickered at the same selectable rates controlled by the microprocessor.

The video mixing and synchronization function mixes the two processed sensor videos to form the composite video waveform. Compensation is provided for the processing delays in each channel depending on the processing selected. Standard black and white as well as color encoding to red-green-blue standards is included. The appropriate delay is also provided for the video blanking and synchronization signals for composite video generation.

6.2.4 System Complexity

Table 12 summarizes the various elements and functions included in the conceptual simultaneous sensor presentation system as well as element

TABLE 12. SYSTEM ELEMENT COMPLEXITY, SIZE, WEIGHT, AND POWER

System Elements	Integrated Circuits	Size Cu. In.	Weight, Lbs.	Power, Watts
A/D Converter	50	144	0.75	10
Modular Digital Scan Converter	1400	1440	21.0	280
• A/D				
• Scan Converter				
• Symbol Generator				
• Microprocessor				
Additional Buffer Memory	1200	1248	18.0	240
Boresight Correlator-N Line	100	192	1.5	20
Boresight Correlator-Area	400	480	6.0	80
Positional Dependent Gamma (2)	40	134	0.6	8
Gain (2)	10	105	0.15	2
Polarity (2)	10	105	0.15	2
Threshold (2)	20	115	0.3	4
Modulation Sample (2)	100	192	1.5	20
Edge Detect (2)	40	134	0.6	8
False Color (2)	20	115	0.3	4
Pseudo Color (2)	70	163	1.0	14
Image Alternation (2)	20	115	0.3	4
Video Mixing	40	134	0.6	8
System (including all enhancement functions)				
• N-Line Correlation	3120	2.5	46.8	624
• Area Correlation	3320 ICs	2.7 Cu. Ft.	51.3 Lbs.	684 Watts

complexity, expressed in terms of number of integrated circuits required. These elements correspond to approximately 47 of the modules presently being developed for the Air Force Digital Avionics Information System (DAIS). Element size, weight and power are also listed. The total system values represent the summation of all elements and functions listed. In practice, only a limited number of these functions would be implemented; however, all are included for completeness. Note that the most complex elements are the microprocessor controlled digital scan converter and the boresight correlator for determining registration errors. The simplification of the system and elimination of the additional buffer memory would significantly decrease system complexity, size, weight and power.

6.3 DESCRIPTION OF TYPICAL SYSTEM OPERATION

To illustrate the order of operation and the high degree of flexibility of the system described in 6.2 and diagrammed in Figure 19, two typical sensor combinations are examined – FLIR/TV for use at short ranges and radar/FLIR for target acquisition at stand-off ranges.

6.3.1 FLIR/TV Simultaneous Presentation

In this example, the FLIR sensor is assumed to be the primary sensor, which is to be augmented by the secondary sensor, i.e., the TV. Thus, the FLIR input represents the reference or baseline and the TV represents the variable.

Referring back to the system diagram of Figure 19, the FLIR video is inputted to the boresight correlator as the reference video. The MDSC input multiplexer selects the TV input and initially performs the A/D conversion. Since the TV and FLIR are compatible in scan pattern (azimuth/elevation), the spatial warping algorithm (first order approximation) is not implemented. The TV data is loaded into the scan converter memory to match the FOV and scan rate of the FLIR. The converted TV video is inputted to the boresight correlator. The correlator measures the boresight offset between the TV and FLIR (horizontal and vertical), the magnification difference, and the rotational error. The horizontal and vertical offsets and magnification differences are sent to the MDSC where the corrections are implemented digitally via position offsets in the digital scan converter

memory. Because rotational error correction is very complex for high data rate orthogonal scan systems, it is recommended that rotational errors, if significant, be corrected in the sensor mechanical or readout alignment. The result of the preprocessing function then is to provide two sensor inputs which are boresighted, and have common FOV and scan rates.

Moving now to the processing function, the FLIR video is inputted as Sensor Number 1 and the TV video is inputted as Sensor Number 2. The gain and polarity required for the desired processing algorithm is selected for the FLIR, and a similar selection is made for the TV. As an example from the shopping list of processing functions shown in Figure 19, the scene modulation sampling operation (Figure 24) can be used for the FLIR such that low detail areas are replaced by the TV video. The edge detection operator (Figure 23) can also be applied to the FLIR to enhance target edges. The false color select can encode the enhanced FLIR edges or outlines in red, while the baseline FLIR imagery is displayed in black and white. The low modulation areas which have been replaced by the TV can be encoded in blue/green.

The processed video outputs are summed in the video mixing/synchronization after the processing delays are compensated. If symbology is desired to represent data from supplementary sources such as warning receivers, GMTI, laser spot tracker, stored and linked threat data, or automatic target cuing devices, the symbol generator output would also be mixed to form the composite video output.

The operations described above apply to a multisensor target acquisition pod containing both a FLIR and TV, or to the synergistic use of acquisition pod sensors and missile seeker sensors. Many attack aircraft do not presently carry both FLIR and TV due to space, weight and cost limitations. The B-52 (EVS) and B-57 (Tropic Moon III) are equipped with both FLIR and LLLTV. The A-6E and A-7E carry FLIR only, and the F-16, F-18, and B-1 may carry FLIR only. A possible means of obtaining TV imagery in an F-18 with FLIR-only target acquisition would be the utilization of a TV seeker in one of its missiles (if the seeker has or were given some slewing capability).

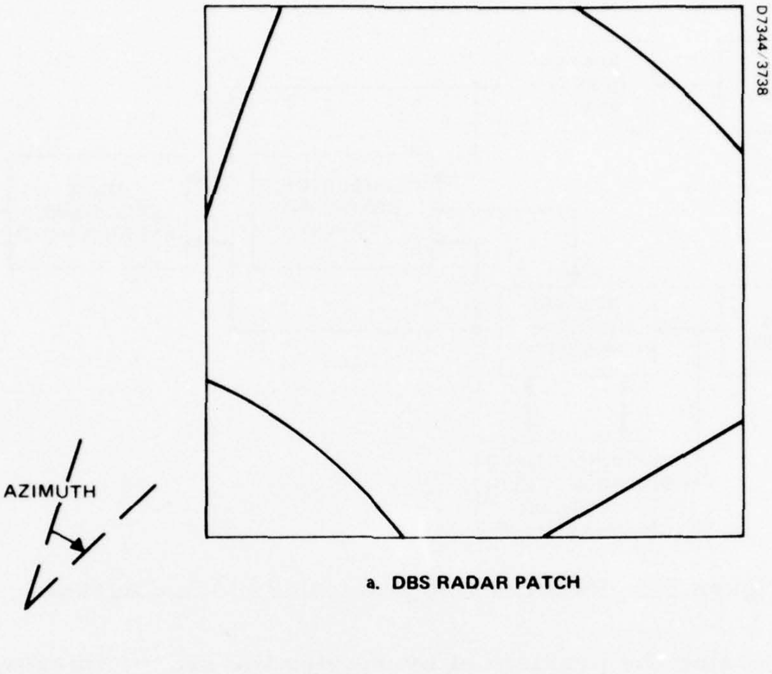
A similar combination of acquisition pod sensor and missile seeker sensor might be envisioned for the Pave Knife/Imaging IR Maverick or the TRAM/TV Maverick.

6.3.2 Radar/FLIR Simultaneous Presentation

In this example, a doppler beam-sharpened (DBS) patch radar mode is the primary or reference sensor and a forward looking infrared (FLIR) imaging system is the secondary or augmenting sensor. Because of gross incompatibilities between these two sensors, the analysis and design presented here represent one of the most difficult problems of simultaneous presentation. One of the aims of this analysis is to show that a careful consideration of the specific nature of the sensors leads to a simpler block diagram with resultant savings in system hardware and complexity at no loss of performance.

The DBS radar image covers a radial segment with approximately 12° FOV and approximate ground dimensions of 4 mi. by 4 mi. at a distance of 20 nmi. as shown in Figure 27. The processing time for each full frame is on the order of 4 sec. The FLIR images cover a smaller FOV, ranging from 3° to 5° down to 1.5°, and each FLIR frame is received in approximately 1/30 sec. Thus, the FLIR data enter at a much faster rate than the radar but correspond to a smaller FOV. The FLIR sensor must then be stepped or scanned in an orderly fashion to cover the same footprint as the DBS patch and the resulting FLIR images overlaid on top of the DBS radar imagery, as shown in Figure 27. In this figure, a 3° FOV is assumed for FLIR vs. 12° for DBS radar, such that approximately 12 FLIR image patches are needed to cover the radar footprint. The major problem here is to determine the correct position of each FLIR patch as it arrives in relation to the DBS radar footprint as well as in relation to the adjacent FLIR patch. In addition, there may be an unintentional relative motion between each FLIR patch and the DBS radar image, so that image correlation is necessary for accurate frame registration. Other sources of error which need to be compensated include static (systematic) sensor misalignment.

A system diagram of a processor to combine these images is shown in Figure 28. The radar data undergo a scan conversion process with a coordinate transformation (polar to rectangular mapping) and storage in a scan conversion buffer memory before display. The buffer memory also serves as a refresh so that a flicker-free 30 frames-per-second image can be seen on a low persistence display. Further image processing for enhancement follows the buffer.



a. DBS RADAR PATCH

b. DBS RADAR PATCH WITH OVERLAID FLIR PATCHES

Figure 27. Superposition of DBS Radar and FLIR imagery.

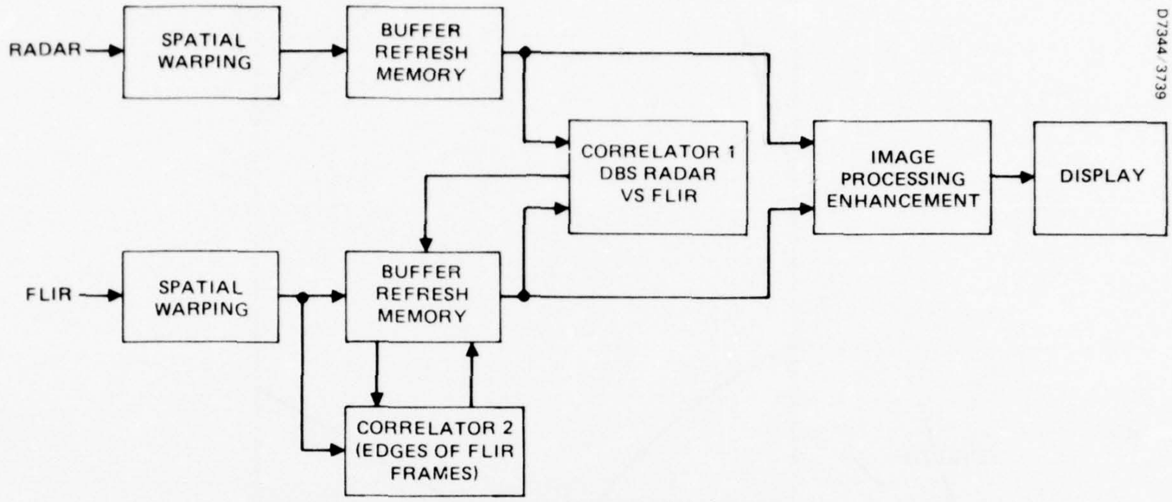


Figure 28. Radar/FLIR processor block diagram.

In addressing the problem of overlaying the sensor images, it is assumed that gross magnification and rotation problems are removed by prior processing or as part of the correlator as described in Sections 5.1 and 6.2. An efficient system requires an additional image buffer memory, since the FLIR data frames enter sequentially as noted in Figure 27 and each frame is synchronized with the DBS radar to scan areas in an overlapping patch work work manner as shown. Each FLIR patch is adjusted to the correct coordinate system and stored in the buffer memory. The first FLIR patch is correlated against the DBS radar in correlator 1 of Figure 28 and is then positioned correctly in the buffer for overlap. When additional FLIR patches arrive (every 1/30th second) they can be positioned in one of two ways. The first way is to use correlator 1 (DBS radar vs. FLIR) and to insert the patch in its appropriate location on the display. The correlation search time should be small for this problem because the FLIR is generally synchronized to a particular local area of the DBS radar and only a small correction is determined by the correlator. A second method is to correlate the edges of overlapping FLIR patches in a smaller correlator (2 on the diagram in Figure 28) and to insert them in the appropriate position. In either method, any overlaps between FLIR patches are resolved by always inserting new data (destroying any old image) into the FLIR buffer memory.

Many FLIR frames can be processed in the time for one DBS radar frame. For the example here, 4 sec/radar frame ÷ 1/30 sec/FLIR frame = 120 FLIR frames entering in the time for one DBS frame. In Figure 28, there are 12 FLIR patches, so each patch can be renewed with new data as many as 10 times per DBS radar frame. This first method (using correlator 1 and discarding correlator 2) has an advantage because succeeding FLIR frames are not tied to the origin established by FLIR patch 1. Thus, strong relative motion, misalignment and other errors can be removed as best as possible before the FLIR data is inserted. Careful synchronism of the FLIR patch scanner with the DBS radar is required to minimize correlation search time. In practice, the buffer memories in Figure 28 may be part of the scan conversion system (including coordinate transformation) or of the correlator, but they are drawn separately for clarity. The decision to combine the buffer refresh memory with various blocks depends on existing hardware subsystems such as the modular digial scan converter that may be available, as well as other digital design considerations.

For almost all practical systems it is necessary to have two separate coordinate transformation and buffer memory systems to null out errors, misalignment and motion effects as noted, unless the radar is already provided in a TV format (as in the F-18 radar). Without the additional coordinate transform and buffer memory system, it is necessary to identify the number of FLIR patch locations from Figure 27 very accurately a priori in relation to the DBS image for accurate image overlay.

An alternate implementation, less accurate but far simpler, is to eliminate the second buffer memory for FLIR data and instead use a symbol generator to indicate hot spots. The FLIR video for each patch or scan location is thresholded, and the location of the FLIR hot spots are transferred to the control microprocessor to generate symbols by means of the symbol generator. The symbols are mixed with the radar video at the hot spot locations and in this manner target points are identified without need of an additional scan converter memory.

The basic requirements are that the FLIR and DBS radar be correlated at some initial position, and the FLIR can then be stepped along in an overlapping patch manner. The FLIR gimbal angles and hot spot (x, y) coordinates at each FLIR line-of-sight position are the only data that need to be accumulated during this process for transfer to the microprocessor. This technique is feasible because the FOV reading rates for the FLIR exceed the DBS reading rates by a factor of over 100 such that the FLIR mosaic of patches can consist of an array of as many as 10 x 10 sample FOV's. The FLIR hot spots can appear as color-coded (red) dots on a black/white or green radar display or as highest intensity, flashing dots on a monochrome display.

The operations described above apply to the synergistic use of an aircraft mounted multimode radar with a pod mounted FLIR target acquisition system. Such combinations are appropriate for intermediate to stand-off range target acquisition and weapon delivery concepts as discussed in Section 4.0

6.4 CONCLUSIONS

A general system implementation has been presented for the simultaneous display of a variety of data. The system accepts inputs from

1. Real-time sensors, such as radar, FLIR, TV, laser spot trackers/rangers, warning receivers, GMTI, etc.;
2. A priori data stored in the aircraft data base, such as reconnaissance imagery from radars, IR sensors, aerial camera, etc., cartography, and prebriefed waypoint/target/threat coordinates;
3. Data-linked target imagery and updated target/threat coordinates.

The general system is designed to handle the most complex case, i.e., the combination of two real-time sensors such as radar and FLIR or FLIR and TV. It can thus readily handle the simpler cases such as radar plus stored imagery and radar plus cartography. The system allows for a multiplicity of processing functions including coordinate transformation, scan conversion, correction for geometric distortions and intensity nonlinearities, determination and correction of registration errors in x, y translation, magnification, and rotation, controllable gain and polarity, a variety of selectable image processing and enhancement operations, selectable color encoding, and a number of video mixing techniques.

Implementation methods have been presented for each of these functions for completeness and to demonstrate the extensive flexibility and capability which could be designed into a multisensor display system. In practice, however, an operational system will undoubtedly implement only a limited number of these operations in an intended application, depending on the types of information to be combined, general performance and accuracy requirements, desired flexibility, and permissable hardware size, weight and power. For example, fine corrections may not be required for geometric distortions or brightness nonlinearities. Strict tolerances may not be required for image registration (in fact, misregistration of images may actually be advantageous). One or two simple image enhancement operations may be sufficient to extract the salient information required from one sensor for display on a second sensor image. Thus, an austere system with a high performance level may be achieved by incorporating only the minimal essential elements with accuracies and tolerances adequate for the specific application.

A comparison of the relative complexity of mechanizing various simultaneous presentations is given in Table 13. The primary sensor is shown for each phase of the interdiction mission, as well as a number of secondary sensors or data to augment the primary sensor. For each combination of primary sensory and secondary sensor or data, the key system elements required to implement that combination are listed. The lowest common multiple of these elements is sufficient to characterize a system capable of being utilized in every mission phase. Also listed are a qualititative estimate of relative system complexity, an estimate of "availability" or time to a flyable brassboard, and those combinations which appear to warrant concentrated effort in the near future.

It should be noted that much of the hardware shown in the general system implementation may already be onboard a high performance tactical aircraft. For example, a digital scan converter may be associated with or contained within the radar equipment (as in the F-18). A control microprocessor, a central data bus, and a symbol generator may also be part of the avionics. All of the above are key elements, for example, in the Navy's Advanced Integrated Display System (AIDS) and the Air Force's Digital Avionics Information System (DAIS).

TABLE 13. COMPARISON OF CANDIDATE MULTISENSOR COMBINATIONS

Mission Phase	Primary Sensor	Secondary Sensor/Data	Estimated Pilot Utility	Estimated Color Desirability	System Elements Needed	Relative System Complexity	Availability Near Term	Availability >3 yr.	Recommended Priority Effort
Cruise/Navigation	Radar • RBGM • DBS • SAR	Cartography	HIGH	HIGH	Projection Display	LOW	X		
					Electronically Generated Display	LOW	X		
					DSC, Correlator, Microprocessor	MOD		X	X
		• Beacon, CP's • Warning Rcvrs • Stored/Linked Threats	HIGH	HIGH	Microprocessor, Symbol Generator	LOW	X		
Preliminary Target Acquisition (Longer Range)	Radar • DBS • SAR	Cartography	MOD	HIGH	DSC, Correlator, Microprocessor	MOD		X	
		Stored Imagery	HIGH	HIGH	A/D, Warping Algorithms, DSC, Correlator, Microprocessor	HIGH		X	X
		• Stored/Linked Target Data • GMTI • Warning Rcvrs • Stored/Linked Threat Data	HIGH	HIGH	Microprocessor, Symbol Generator	LOW	X		
Target Acquisition (Stand-off Range)	Radar • DBS • SAR	FLIR • Hot Spots	HIGH	HIGH	FLIR Thresholding Circuit, Microprocessor, Symbol Generator	MOD	X		X
					A/D, Boresight Correlator, FLIR Thresholding, DSC, Microprocessor	HIGH		X	
		Automatic Feature Extraction/Pattern Recognition Devices	HIGH	MOD	Very Sophisticated Processor, Symbol Generator	MOD TO HIGH	X MOD Comp. High False Alarm	X HIGH Comp. Low False Alarm	
		• Laser Spot Tracker/Ranger • GMTI • Warning Rcvrs • Stored/Linked Tgt/Threat Data	HIGH	HIGH	Microprocessor, Symbol Generator	LOW	X		
Run-In to Target	Radar • Terrain following template or steering commands	FLIR • Imagery	MOD	MOD	Microprocessor, Symbol Generator	LOW	X		
	Radar • Terrain avoidance range-coded contours (C-scan)	FLIR • Imagery	MOD	MOD	Boresight Correlator, Radar Range-interval Processing, Microprocessor, Symbol Generator	MOD		X	
Target Acquisition (Stand-off to Minimum Range)	FLIR • Imagery	RADAR • GLINTS	MOD	HIGH	A/D, Boresight Correlator, Radar Thresholding, Microprocessor, Symbol Generator	MOD		X	
		TV • Imagery	HIGH	HIGH	A/D, DSC, Boresight Correlator, Microprocessor, Image Processing, Mixing	HIGH		X	X
		Automatic Target Cuing Devices	HIGH	HIGH	Complex Processor, Symbol Generator	MOD TO HIGH	X MOD Comp	X HIGH Comp	X
		• Laser Spot Tracker/Designator Ranger • Warning Rcvrs • Stored/Linked • Tgt/Threat Data	HIGH	HIGH	Microprocessor, Symbol Generator	LOW	X		

A boresight correlator may also be an onboard requirement to

1. Coordinate the radar and target acquisition FLIR (or TV) for navigation updates and fire control functions, and
2. To boresight the missile sensor (imaging IR, quasi-imaging IR, TV, or imaging microwave) to the pilot's target acquisition sensor (FLIR or TV) for target hand-off.

Therefore, there is a well-defined and widely acknowledged need for weapon system requipment to correlate very diverse types of imagery in real-time. Because the simultaneous presentation of several sensor data on a single display also requires the correlation of dissimilar imagery, the same hardware and software being developed for target hand-off is directly applicable to that needed for implementation of the multisensor display concept.

Thus, the addition of a simultaneous presentation capability need not mean a major addition of avionics. Also, all of the elements identified in the general system represent equipment that is already available or presently in development.

In estimating the complexity of this equipment, emphasis was placed on Hughes' related engineering experience. A sizable number of the elements in the general system are presently in development at Hughes, including

- The An/UYK 30 microprocessor developed with company funds and Air Force and Navy support,
- The microprocessor-controlled modular digital scan converter (including symbol generator and central data bus) developed for AFAL and flight-tested in 1976,
- The in-raster symbol generator developed for NADC and delivered in 1976,
- The N-line boresight correlator and the more sophisticated area boresight correlator developed on company support.

Hughes is also the prime contractor on the DAIS program to build an integrated cockpit display system for the Air Force's "hot bench" facility. Thus, the suggested implementations for the multisensor display system are based on state-of-the-art equipment whose capabilities and interfaces are well understood.

7.0 OBSERVATIONS AND CONCLUSIONS

This study has examined the simultaneous presentation of multisensor data on a single display in terms of potential utility to the pilot and estimated complexity of implementation.

The following paragraphs summarize pertinent observations which were made during the conduct of this study, major conclusions which emerged as a result of the study, and essential efforts which are required in the future to confirm and quantify those conclusions.

1. From the interdiction mission analysis, it is apparent that the pilot in a single-seat, high-performance attack aircraft is faced with an increasing, if not overwhelming, amount of information which must be perceived, assimilated, and mentally integrated for required judgments to be made and appropriate action to be taken. These tasks are intensified during critical portions of the mission such as target acquisition and weapon delivery, and are further intensified during night operations.

2. From the sensor capabilities/target characteristics survey, the advantages of multiple sensors in target acquisition and weapon delivery are evident. This is due to the multi-attribute nature of targets which makes them detectable in a number of different spectral regions (passively or actively) and thus by a number of different sensors. The attributes can be time critical so that if one signature ceases, another signature may remain detectable by means of multisensor capability.

3. From the analysis of operator tasks as a function of mission phase and the subsequent determination of the baseline sensors which could be utilized to perform those tasks, the following observations can be made.

   - There is no one sensor which provides sufficient information to act as the principal or lead sensor throughout the mission.
   - Instead, a single primary sensor typically emerges for each mission phase to provide the basic information required at that time. A set of secondary sensors and collateral data are available to supplement the primary sensor information and thereby provide target cuing, target verification, threat warning and other valuable data to assist in target acquisition or defensive action.
   - Also, there is typically no smooth transition from the primary sensor information of one phase to the primary sensor information of the next phase. Conflicts and gaps can and do exist between sensors.

4. The simultaneous presentation of multisensor data on a single display represents one possible technique for

   a. Assisting the operator in integrating a multiplicity of essential data.

   b. Increasing the probability of successful target acquisition and weapon delivery, and

   c. Improving aircraft survivability.

   A major premise in the simultaneous sensor presentation concept is that primary sensors and secondary sensors/collateral data can be synergistically combined within useful time periods, i.e., mission phases. However, the differences between sensor capabilities and the gaps encountered when transitioning from one primary sensor (mission phase) to the next must somehow be resolved, either by introducing a priori knowledge, by utilizing additional sensors, or by further refining target identity and location by some other means. This is based on the following observations:

   - A priori data, i.e., target data and enroute threat data compiled before take-off for prebriefed missions and entered into the A/C data base, can be of major assistance within each mission phase and greatly contribute to pilot performance and overall mission success.

   - The primary real-time sensor for each mission phase can typically be aided by one or more additional sensors which are able to provide some type of augmenting information at the primary sensor's operational range. Each of the sensors combined would thus contribute its strongest range-compatible target acquisition trait.

   - Advanced target location and identification techniques are being pursued which may facilitate the target acquisition problem in the future. These include a) the processing of two sensor outputs such as synthetic aperture radar returns and ELINT system line-of-bearing for greatly improved accuracy and timeliness of emitter targeting, weapons allocation or threat avoidance maneuvers; and b) the processing of sensor video for feature extraction and pattern recognition of rivers, roads and eventually, tanks, trucks, etc., for target cuing purposes.

5. During the conduct of the study, several promising simultaneous sensor/sensor and sensor/a priori data display candidates emerged for use in an interdiction mission. The sources considered for simultaneous presentation included

   a. Real-time sensors such as radar, FLIR, TV, GMTI, radar/laser warning receivers, laser spot trackers/rangers, etc. and

   b. A priori (stored) data such as target and known threat coordinates, cartography, and reconnaissance imagery of the target area (photo, radar, IR, laser linescan, etc.).

Many of these combinations were simulated by means of static imagery and qualitatively evaluated in terms of potential utility to the operator. The most promising combinations which emerged are listed in Table 14 as a function of mission phase. The table associates the primary imaging sensor for each phase, the secondary imaging sensor, and a number of supplementary sensors and collateral data which can be displayed by means of overlaying symbology on primary sensor video. Provision was also made for future incorporation of automatic feature extraction and target cuing devices, whose output can also be displayed as a symbol overlay.

Those imagery candidates which appear to warrant further investigation include: the simultaneous presentation of radar and cartography for navigation; radar and stored target imagery (or maps) for preliminary acquisition of large, fixed targets; radar and FLIR hot spots for preliminary acquisition of targets of opportunity; and FLIR and TV for closer range target recognition and identification (and correlation hand-off of targets).

6. Implementation of the most promising simultaneous sensor presentations can be effected using hardware/software elements which either have been or presently are being developed. All operations should be capable of being performed in real time with sufficient accuracy for this application. Definite advantage can be taken of avionic subsystems and processors already onboard such as the A/C mission computer, the radar scan converter, the boresight correlator used for target handoff to missile sensors, etc.

During the course of the study, a general implementation concept was identified for taking two video inputs (selected from real-time radar, FLIR, and TV sensors, or stored/linked imagery), making them format and scan-line compatible, correcting for registration errors, performing any desired enhancement operations, and mixing the two registered, processed video in an optimum manner for simultaneous display. This general concept is modular in nature and highly programmable. It performs the various correction operations sequentially and then provides for a number of selectable image processing and display techniques.

Not all elements in the general implementation are required for any single combination. Thus, the system could be greatly simplified depending on the particular multisensor combination desired. Those elements required to implement each of the recommended simultaneous presentations of Table 14 were identified during the study and rated in terms of complexity and estimated date of flyable brassboard model availability. The most complex elements are the microprocessor - controlled digital scan converter and the image registration computer (boresight correlator), both of which are presently in development at Hughes.

TABLE 14. RECOMMENDED MULTISENSOR COMBINATIONS

Mission Phase	Primary Sensor	Secondary Sensor/ Data	Supplementary Sensors/Data
Cruise/Navigation	Radar Imagery • RBGM • DBS • SAR	Cartography	Symbology • Beacon • Prebriefed CP's • Warning Receivers • Stored/Linked Threat Data
Preliminary Target Acquisition • Long Range	Radar Imagery • DBS • SAR	Stored Imagery of Target Area	Symbology • Stored/Linked Target Data • GMTI • Warning Receivers • Stored/Linked Threat Data
• Intermediate Range	Radar Imagery • DBS • SAR	FLIR • Hot Spots	Symbology • Feature Extraction/Pattern Recognition Devices • Laser Spot Tracker/Ranger • GMTI • Warning Receivers • Stored/Linked Target/ Threat Data
Target Acquisition at Pop-Up • Stand-off Range	FLIR Imagery	Radar • Glints	Symbology • Automatic Target Cuing Devices • Laser Spot Tracker/Designator/ Ranger • Warning Receivers • Stored/Linked Target/Threat Data • GMTI, GMTT
• Stand-off to Minimum Range	FLIR Imagery • Processed	TV Imagery • Processed	

7. While the most promising simultaneous presentations can be implemented using a monochrome display, color coding of the various sensor/data inputs may assist the operator in performing certain tasks. On a monochrome display, secondary sensor highlights or a priori data may be distinguished from primary sensor video by being displayed at highest intensity and perhaps intermittently flashed; also, shape-coded symbology can be used. If a color display were provided, sensor highlight information, graphics, and symbology could be color-coded when overlaid on primary sensor imagery. A human factors evaluation would be required to quantify any improvement in operator performance using multicolor presentations versus monochrome.

   Present cockpit displays are monochrome; however, there are ongoing efforts in the area of militarized multicolor displays such as ruggedizing the shadow-mask CRT and improving the performance of the penetration phosphor CRT. The development of the latter would provide a 2 to 3 color display with gray scale capability, which would be sufficient for this application, and most likely easier to achieve than a militarized full color, full gray level display. Future efforts may take advantage of advanced flat panel display technology such as the matrix-addressed liquid crystal pictorial display.

8. In conclusion, a qualitative evaluation of an extensive number of potential simultaneous data presentations, based on estimated utility to the operator and complexity of implementation, has resulted in several candidate combinations which are recommended for further study. In terms of usefulness to the operator, these candidates offer the potential of improved target acquisition, weapon delivery, and survivability without an increase in task load. In terms of implementation, the most complex hardware and processing elements required are already scheduled for inclusion in advanced attack aircraft avionics.

9. In regard to recommended future efforts, a significant problem was encountered in this study and in previous efforts uncovered in the literature survey, i.e., the lack of usable, coincident coverage, multispectral imagery (static or dynamic). Without such imagery, no quantitative evaluation of performance improvement associated with multisensor displays can be made. Therefore, three major recommendations for future effort emerge:

   - That a data base of simultaneous, coincident coverage multisensor imagery be acquired using real-time, high performance sensors, including radar, FLIR and TV.
   - That a brassboard model of key elements in the multisensor display concept be assembled, using off-the-shelf components and incorporating the various image enhancement functions, to simulate the most promising multisensor combinations recommended in Table 14 and to determine the optimum interfacing of the subsystems.

- That a human factors evaluation of the recommended multisensor presentations be conducted (initially static, ultimately dynamic) to 1) quantify the anticipated improvement in operator performance over single or sequential sensor use; 2) quantify the permissable tolerances in corrections for geometric distortions, intensity nonlinearities, and misregistration (slight misregistration of images may actually enhance target acquisition); 3) evaluate the effects of the various image enhancement operations on target acquisition; and 4) investigate the anticipated performance improvement in false color coding of the multisensor inputs.

10. Should these three recommendations be implemented, it is expected that the simultaneous presentation system capabilities will be sufficiently well-characterized that the concept can be readily extended and applied to a variety of missions. It is also expected that system operation for these missions will be highly automated. On a prebriefed mission, for example, the sequencing of simultaneous presentations can be preselected, typically as a function of mission phase. Also, the processing and image enhancing operations associated with each sequential simultaneous presentation can be preprogrammed. Thus, operator interaction and task load can be minimized, while allowing for operator override in all cases.

    The system of the future can be envisioned as totally adaptive to the mission objectives, mission profile, and operator requirements. All simultaneous presentation functions will be coordinated by the mission computer. The selected types of targets, the anticipated backgrounds in which those targets are embedded or surrounded, the selected mission profile, and meteorological conditions encountered along that profile will be entered into the mission computer. Stored algorithms will determine the optimum combination of primary/secondary sensors for each mission phase, will automatically sequence and switch the combinations as a function of phase throughout the mission, and will select the optimum processing operations for image enhancement and image understanding as a function of sensor combination and mission phase. Operator interactive control of the system will be provided, as well as override capability.

    This automated, adaptive simultaneous presentation system of the future can free the operator to concentrate on the essential tasks of mission management, critical decision making, and offensive/defensive systems supervision. The study has determined that such a system of the future is technically feasible.

8.0 GLOSSARY OF TERMS AND ABBREVIATIONS

AAA	Anti-Aircraft Artillery
A-A	Air-to-Air
ADC	Air Data Computer
AFAC	Airborne Forward Air Controller
A-G	Air-to-Ground
AGR	Air-to-Ground Ranging
AIM	Air Interceptor Missile
CAP	Combat Air Patrol
CAS	Close Air Support
CBU	Cluster Bomb Unit
CP	Checkpoint
CPU	Central Processor Unit
DBS	Doppler Beam Sharpening
ECM	Electronic Counter Measures
ELS	Emitter Location System
EO	Electro-Optical
FAC	Forward Air Controller
FAE	Fuel-Air Explosive
FLIR	Forward-Looking Infrared
FOV	Field of View
FTI	Fixed Target Indication Radar
FTT	Fixed Target Track
GMTI	Ground Moving Target Indication
GMTT	Ground Moving Target Track
GPS	Global Positioning System
HARM	High Velocity Anti-Radiation Missile
HMD	Helmet-Mounted Display
HUD	Head-Up Display
IFF	Identification, Friend or Foe
ILS	Instrument Landing System
INS	Inertial Navigation System

IP	Identification Point
IR	Infrared
JTIDS	Joint Tactical Information Distribution System
LATV	Laser-Aided Television
LLLTV	Low Light Level Television
LOC	Line of Communication
LOS	Line of Sight
LORAN	Long Range Navigation (System)
LWR	Laser Warning Receiver
MTI	Moving Target Indication Radar
NCTR	Non-Cooperative Target Recognition
OTH	Over The Horizon
PELSS	Precision Emitter Location and Strike System
PPI	Plan Position Indicator
PRF	Pulse Repetition Frequency
PTS	Photogrammetric Targeting System
RAM	Random Access Memory
RBGM	Real Beam Ground Map
RWR	Radar Warning Receiver
RWS	Range While Search
SAM	Soviet Air Missile
SAR	Synthetic Aperture Radar
SLAR	Side-Looking Airborne Radar
STT	Single Target Track
TA	Terrain Avoidance
TACAN	Tactical Aircraft Navigation (System)
TF	Terrain Following
TOA/DME	Time of Arrival/Distance Measurement Equipment
TRAM	Target Recognition/Attack Multisensor
TWS	Track While Scan
TEREC	Tactical Electronic Reconnaissance Set
TASES	Tactical Airborne Signal Exploitation System
UGS	Unattended Ground Sensor
USS	Unattended Sea Sensor
VTAS	Visual Target Acquisition System
WRCS	Weapon Release Computer System

APPENDIX A
SURVEY OF MULTISENSOR STUDY LITERATURE

A key objective in the investigation of simultaneous sensor presentations is improved operator task performance. Any simultaneous sensor display concept must therefore provide sufficient potential for operator performance improvement if it is to be considered for development, testing and, eventually, implementation in operational military aircraft.

A number of simultaneous sensor presentation techniques are identified in Section 4 of this report. It is not possible to analytically determine what performance improvement might be achieved with the various techniques identified. Empirical quantitative evaluation is the necessary method to assess the performance improvement that can be achieved with multisensor display techniques. Such an evaluation was beyond the scope of this study. In this study, two techniques were employed to provide a preliminary assessment of the potential of the simultaneous presentation concept for performance improvement. These two techniques were 1) a review of the literature and 2) a qualitative evaluation of selected simultaneous sensor presentation techniques by means of synthesized static imagery. The literature review of behavioral (operator performance) studies in the area of simultaneous sensor presentation is presented below. Samples of the synthesized imagery are presented in Section 4.

Fourteen operator performance studies relevant to multisensor display were culled from Defense Documentation Center and Hughes bibliographic literature searches. The presentation of these studies is organized into two major categories: 1) multiple real-time sensors, and 2) one real-time sensor and one or more non-real-time sensors. Non-real-time sensors are defined here as pre-mission information, such as target location data, maps, photos, and other reconnaissance/intelligence data. Presentation technique was used as a second level categorization of the studies reviewed. Simultaneous multiple sensor presentation on a single display, simultaneous multiple sensor presentation on multiple displays, and sequential multiple sensor presentation on a single display were the three presentation technique categories used.

Radar was the primary sensor in a large percentage of the studies reviewed. This is due to a fair amount of research interest in briefing and reference materials and target pre-designation (non-real-time sensors) for air-to-ground radar strike systems.

A.1 MULTIPLE REAL-TIME SENSORS

A.1.1 Simultaneous Presentation on a Single Display

Two studies were located which investigated simultaneous sensors presented on a single display. The more interesting of the two studies (Stinnett, Leonard, and Farehert, 1969) investigated five display presentation modes for common aperture TV and IR video. The second study (Green and Kalensher, 1972) investigated 0.4880 to 10.6 micrometer multispectral line scan imagery for tactical target cueing.

The Stinnett, Leonard, and Farehert (1969) study evaluated simultaneous TV and FLIR sensor presentation techniques for vehicle detection and recognition. The two sensors had a common aperture and a 5-degree field of view with 100 by 100 element resolution. The five display presentation modes studied were:

1. TV only in black and white
2. IR only in black and white
3. TV and IR superimposed in black and white
4. TV displayed in blue-green, IR inserted by contour fill displayed in red
5. Same as 4) with IR alternated (on-off) at a 2 Hz rate.

A truck, a Ford, and a Volkswagon, each located in three background scenes, provided the sensor imagery for the study. The vehicle targets were driven across a dirt road at 10 mps in the three scenes; these moving targets were recorded on video tape at ranges between 1900 and 3300 feet for use in the study. Thirty observers participated in the study — six observers for each of the five display presentation modes.

The results, time and probability of target detection and recognition, revealed that operator target detection performance was not differentially affected by the five display modes. In other words, the observers detected the targets about equally well regardless of whether TV, IR, or combined TV and IR were displayed.

Target recognition performance (time and probability) was, however, differentially affected by the five display modes evaluated. Figure A-1 shows target recognition time and probability performance with the five display modes. IR only was superior to TV only, and TV and IR superimposed was inferior to IR only. The best target recognition performance was achieved with the two modes in which TV was displayed in blue-green and IR was inserted in red. Performance was slightly better when the 2 Hz alternation was used. Comparison between IR only and TV with IR inserted shows a 57 percent increase in target recognition probability and a 17 percent decrease in time to recognize using the multisensor TV and IR mode.

The results of the Stinnett, Leonard, and Farehert (1969) study clearly indicate the potential for improved operator performance with simultaneous sensors. It is also clear that to achieve a performance improvement, simultaneous sensors must be properly formatted and displayed — improperly superimposed TV and IR can and does degrade performance compared to single sensor presentation.

It should be pointed out that there are limitations in the study. The use of three background scenes and three targets must have made it unrealistically easy for the observers to search the scenes and detect and recognize the targets. The use of six observers per condition is too small a sample to assume equivalent groups. There is, therefore, some uncertainty whether observed differences among display modes were due to observers within the five groups of six display modes or the display modes themselves. A final criticism is the relatively small sensor field of view and short range, probably necessary because of the low sensor resolution, which resulted in scenes with an unrealistically small terrain coverage, particularly for a search and detection task. Notwithstanding these limitations, the study provides the only operator performance information available on simultaneous TV and IR video presented on a single display.

The Green and Gale (1972) study was a rooftop laboratory demonstration of a multispectral scanner. A laser line scanner produced imagery at six different wavelengths from 0.4880 to 10.6 micrometers, and an IR line scanner produced imagery in the spectral region from 1 to 5.5 and 8 to 14 micrometers. A specially designed processor was programmed to "find" military objects (canvas and army uniforms) in a target scene that contained

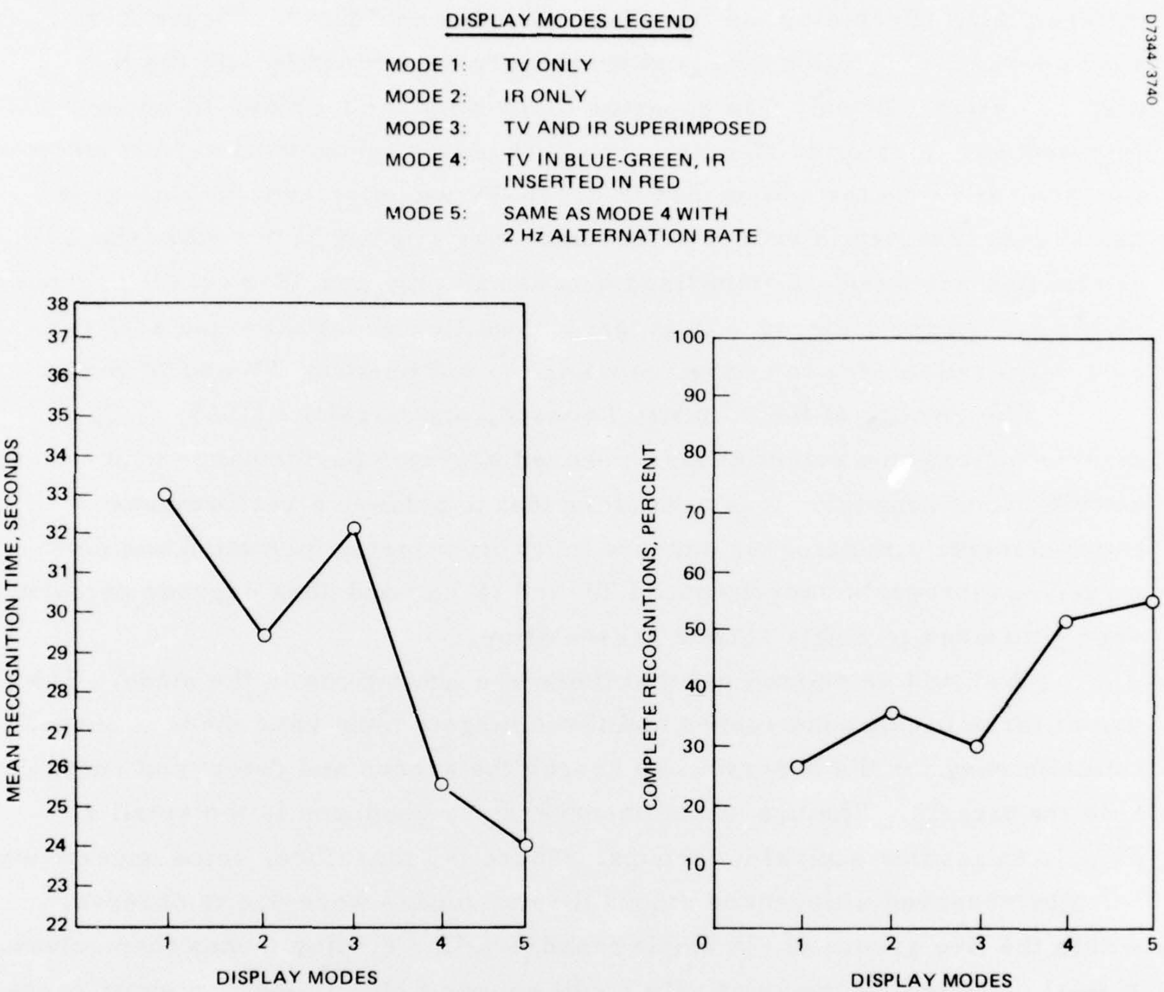


Figure A-1. Target recognition results from Stinnett, Leonard, and Farehert (1969) study.

foliage, sand, ponds, a dirt road, and a number of military equipment items. The target scene was constructed in a lot adjacent to the rooftop laboratory.

The imagery was recorded on black and white as well as color film. False color images were generated by assigning different sensor wavelength bands to different colors. For example, the cue canvas materials, spectral signatures for olive drab canvas were assigned to red; all other spectral signatures were presented in green.

According to the authors, "The results of the work were very encouraging." Of the 15 canvas and army uniform targets, the processor correctly found 12 of the targets. There were four false detections. The preliminary results obtained indicate that a multispectral sensor system can be developed

that can automatically find selected targets in real-time. The targets found by the automatic system could be cued to an operator for more detailed examination or other action. The basic concept appears to be feasible and the potential for improved target detection by a man-machine system looks promising.

A.1.2 Simultaneous Presentation on Multiple Displays

Studies by Snyder, Earl, Wyman, and Sturm (1966) and Leachtenauer, Jones, Iden, and Cook (1968) investigated simultaneous presentation of multiple sensors on multiple displays. Snyder, Earl, Wyman, and Sturm investigated 11 combinations of radar, IR, TV, and direct vision. The radar had 500-feet range resolution and 3.6-degree azimuth resolution. The IR had a 45-degree field of view with 3-milliradian resolution, the TV sensor was a standard 525-line system with a 27-degree field of view. The color direct vision imagery was shown at a 53-degree field of view. The four sensors were optically displayed via 16-mm motion picture film on separate dedicated displays in a single-seat cockpit simulator. (The direct visual scene was back-projected onto a screen outside the cockpit. The TV, IR, and radar sensor imagery was back-projected onto screens in the cockpit.)

The 44 Air Force fighter pilots who were operators in the study were tasked to recognize prebriefed location known targets, e.g., bridges, reservoirs, and industrial complexes. Briefing packets were used for pre-trial study and reference during the trials.

Figure A-2 shows the percent correct target recognition achieved with the 11 combinations of forward view (direct vision), TV, IR, and radar sensors investigated. Best performance was achieved with forward view/IR and forward view/radar combinations (65 to 70 percent recognition); radar alone produced the poorest performance (9 percent correct recognition). Although the forward view/IR and forward view/radar sensor combinations resulted in larger percentage of targets recognized than TV only or forward view only, the differences (15 to 20 percent) were not statistically reliable. There is, therefore, some uncertainty about the performance advantage of simultaneous multiple sensors displayed separately.

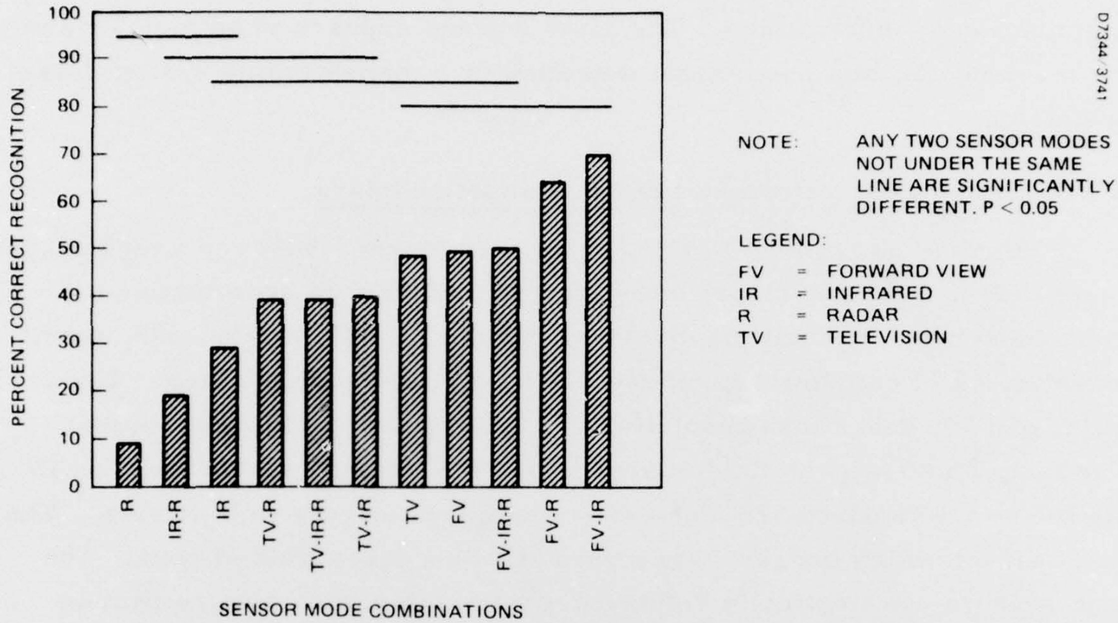


Figure A-2. Target recognition results from Snyder, Earl, Wyman, and Sturm (1966) study.

According to the authors, "The results clearly indicate that the addition of IR or radar or both to any sensor combination which includes either visual sensing or TV does not significantly affect performance either by TV or by direct vision. Apparently the pilot devotes primary attention to the visual or TV scene if it is available and only supplements either of these displays slightly by reference to the IR or radar. If neither the TV nor the direct vision mode is available, IR is more useful than radar — at least for the targets used in this study."

Leachtenauer, Jones, Iden, and Cook (1968) investigated the property of one type of sensor to enhance critical objects and focus attention on corresponding areas of imagery obtained from a different sensor for application to intelligence extraction. Four sensor combinations were investigated:

1. Fixed target side-looking radar (SLR) to focus on photography
2. SLR moving target indication (MTI) to focus on photography

3. SLR to focus on IR
4. IR to focus on photography.

Three presentation orders of the two sensors (focuser sensor and focused upon sensor) were also investigated in the study. These were 1) focuser first, focuser second, and focuser and focused upon sensor images simultaneous. The actual sensor imagery was APQ-102 SLR, AN/AAS-18A IR, and KS-72 forward oblique aerial photography.

Nine image interpreter operators viewed the imagery combinations on a light table. Time, accuracy, completeness, and efficiency of operator image interpretation task performance were measured.

Except for one condition (fixed target SLR to focus on photography), focusing techniques did not improve operator performance, and the authors state that the positive SLR/photo results may have been an experimental artifact. Interpretation time was shorter when the focuser was presented first; however, the shortest times occurred when no focuser was used.

Although the two studies which investigated simultaneous sensor presentation on multiple displays represent a small sample and are limited in application by the sensor imagery available in the mid- to late 1960's, the indication is clear. Presenting multiple simultaneous sensors on multiple displays is not likely to appreciably increase the probability of the operator finding targets and will increase the time to find targets. At best, the operators attend to the sensor most preferred for the task and ignore the other sensors.

A. 1. 3 Sequential Presentation of Real-Time Sensors

A fairly recent concept for multisensor applications is using one sensor to cue a second sensor. A likely application of this concept is imaging radar to cue an electro-optical (EO) sensor. This concept takes advantage of the long range sensing inherent to the radar and the high resolution characteristic of EO sensors.

Humes, Craig, Poplawski, and Hershberger (1974) conducted a laboratory study of synthetic aperture radar (SAR) image quality requirements for cueing an EO sensor. The operator's task in the study was to locate a predefined target area on the radar ground map. The accuracy, in ground feet, of locating and designating the target area was used to

analytically evaluate the feasibility of using SAR for cueing EO sensors. Analyses were performed to relate operator radar designation accuracy to EO sensor field of view, slant range to target, and transverse distance across the EO sensor field of view as illustrated in Figure A-3.

The conclusions drawn from the laboratory research and analysis are as follows:

1. To gain any advantage in a combination cueing radar/EO system, the radar cueing designation error should not exceed 1500 feet. This can be achieved with 20- to 40-foot resolution radars using area designation. Direct designation of a target or designation of an offset cue point yields the smallest error.
2. Small cueing errors will allow small EO fields of view which can increase the probability of recognizing EO targets at long range.
3. Electro-optical fields of view on the order of 3 degrees or less are required for long range (30,000 feet) recognition of small tactical targets. (Meteorological effects at such ranges were not considered in the analysis.)

Sequential presentation of real-time sensors may well be an important multi-sensor application. Radar as an EO cueing sensor appears to be one of the more promising techniques. Man-in-the-loop simulation should be performed to determine the extent of improved operator tactical target acquisition performance with sequential sensor presentation.

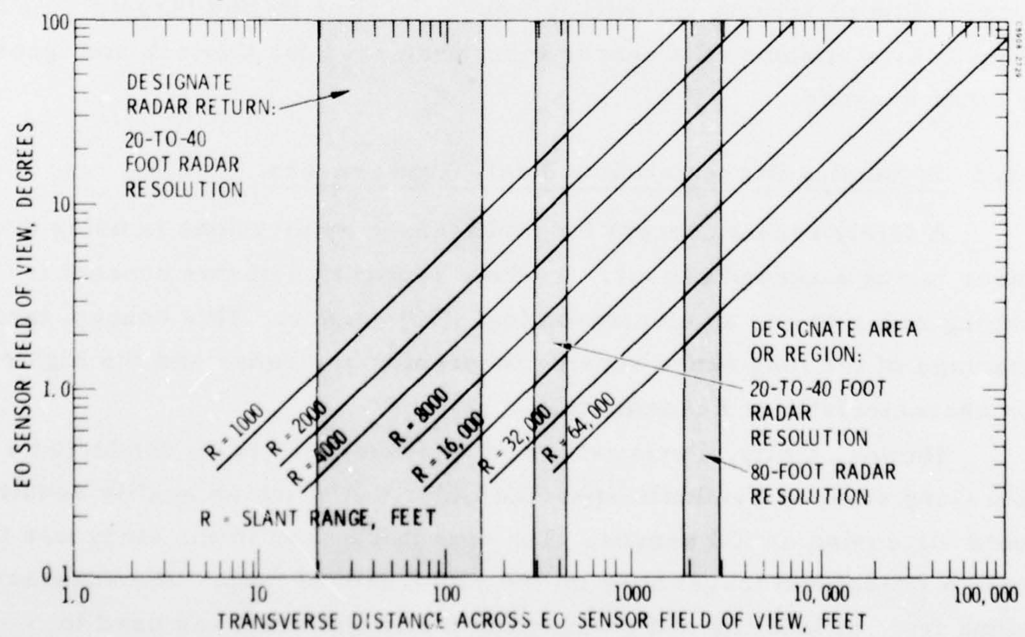


Figure A-3. Relationship among, radar designation accuracy, EO sensor field of view, slant range to ground, and transverse distance across EO sensor field of view.

A.2 ONE REAL-TIME SENSOR AND ONE OR MORE NON-REAL-TIME SENSORS

A.2.1 Simultaneous Presentation on a Single Display

Three papers that treated the use of non-real-time sensor information with a real-time sensor to improve operator performance were found during the literature search. Two of the papers dealt with superimposing cartography on ground map radar video. The third paper investigated the effect of target predesignation on operator target recognition performance.

Habbarth (1957, 1958) compared side-by-side, sequential, and superimposition presentation of 1:500,000 scale Sectional Aeronautical Charts with simulated 30-nautical mile range scale B-52 ground map radar imagery. The operators' tasks in the laboratory studies were to locate and designate prebriefed radar targets.

Superimposition of the charts over the radar imagery produced the best overall time and accuracy. Chart presentation mode was found to interact with the type of radar target. The side-by-side chart and radar presentation technique was best for highly articulated targets; superimposition of chart and radar data was best for no show targets.

Ferranti Ltd. has developed a combined (superimposed) radar/map display for the Harrier Aircraft (Braid, 1971). Matching the map to the radar is done by the operator who slews the map to match terrain features on the radar. The matching process takes a maximum of 10 seconds.

Airborne evaluation of the combined radar/map display produced positive results. The simultaneous display of radar and map data eliminated gross navigation errors and permitted positive identification of radar features. These advantages are achieved by map fill-in of the radar where shadowing and weak returns occur. Another benefit is that one display satisfies both radar and map display requirements.

The use of navigation system or other information sources to provide target predesignation was investigated by Sturm, Snyder, and Wyman (1966). The effects of target predesignation on both direct visual and radar target search were investigated. Predesignation was done by placing a crosshair at the expected location of the target. The operators' task was to recognize prebriefed large fixed targets. Probability of correct target recognition

increased 20 percent and 11 percent for the visual and radar targets, respectively, when target predesignation was used.

For the three papers reviewed, simultaneous presentation of real- and non-real-time sensor data on a single display resulted in improved operator performance. For the prebriefed target mission, this simultaneous sensor application appears very promising. With today's sensor, processing, and display technology, it would seem that considerable improvement in operator performance could be achieved by integrating real- and non-real-time sensor data on a single display.

A. 2. 2 Simultaneous Presentation on Multiple Displays

Several laboratory research investigations have been performed to determine the benefits of and the design requirements for briefing and reference material used with high resolution ground mapping radar (Cahill and Luce, 1967; Carel and Hershberger, 1967; Humes, Craig, Poplawski, Guerin, and Hershberger, 1974; Kause, 1968; McKechnie, 1968; McKechnie, 1969; Welch and McKechnie, 1964. All but one of the studies (Welch and McKechnie, 1964) showed improved performance when the operators were provided briefing and reference material (maps, charts, reconnaissance photography, prior radar coverage) and/or target location information. Generally speaking, the greater the similarity between the non-real-time sensor data and the real-time sensor and the greater the information about the target's location, the greater the improvement in operator target acquisition performance.

In the Welch and McKechnie (1964) study, for example, the operators were required to identify all airfields, bridges, tank farms, power lines, and railroad yards on moving (3. 3 inches per minute) side-looking radar imagery. Sectional Aeronautical Charts were the briefing and reference materials used. For the charts to be of any benefit, the operators had to find targets on the chart provided and then correlate the chart to the radar image, during which time the radar image was moving across the display. Such a process is difficult and time consuming. It is not surprising that the operators did no better at identifying targets when charts were available.

Providing specific target location information (target cueing) on the chart can, however, significantly improve the operator's performance. In a

study procedurally very similar to Welch and McKechnie (1964), McKechnie (1968) found that circling the targets on charts increased the probability of correctly finding the targets by 39 percent.

Simultaneous presentation of real-time and non-real-time sensor data on multiple displays can be beneficial to operator/system performance. Information that can be provided from non-real-time sensors possesses the potential for improved operator real-time sensor task performance. Displaying such non-real-time sensor data on a separate reference display is a satisfactory approach. However, the displayed information must be presented in such a manner that the operator can efficiently utilize it.

A.2.3 Sequential Presentation of Real- and Non-Real-Time Sensor Data

Sequential presentation of real- and non-real-time sensor data does not seem to be a particularly viable multiple sensor presentation technique. Non-real-time sensor data may be presented prior to the real-time sensor, but it should be retained for use during the time the real-time sensor is being displayed. Straight sequential presentation of non-real-time and real-time sensor information is likely to be of little practical utility. This opinion is confirmed by a laboratory research study (Hubbarth, 1957) in which sequential, side-by-side, and superimposition presentation of Sectional Aeronautical Charts and simulated B-52 ground map radar were evaluated. Sequential presentation resulted in the poorest operator target acquisition performance of the three techniques. Straight sequential presentation of non-real-time and real-time sensors can therefore be eliminated as a major contending technique for multisensor presentation.

A.3 CONCLUSIONS AND RECOMMENDATIONS

The preceding review of the literature indicates that multiple simultaneous sensor presentation techniques do hold promise for improved operator task performance. This improved performance may be achieved with multiple real-time sensors as well as combinations of real- and non-real-time sensors. Simultaneous multiple sensors presented on a single display appears to be the best presentation technique, however, it is also the most challenging. Simple addition of two imaging sensors will most likely degrade operator performance, not enhance it. Similarly, displaying real-time sensor video from two sensors on two displays is not likely to improve

operator task performance. The key is integration of sensor information, not simple increases in quantity of information. Providing more information may serve only to increase the operator's processing time and make his task more difficult.

The 14 papers reviewed are, in sum, discouraging — not so much in individual quality, but rather the lack of definite direction in developing any particular area. The 14 papers represent a large breadth of research but little depth. Thus, one cannot really recommend any particular application of a simultaneous sensor presentation technique. Simultaneous sensor presentation techniques are, we think, a fruitful area for improving operator task performance. Better, more definitive research, however, will be required before such techniques are adequately defined and developed for airborne military aircraft.

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